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FERTILIZERS AND NUTRITIVE VALUES OF HAYS.
I. SULPHUR-DEFICIENT GREY WOODED SOILS[1]

C. F. BENTLEY[2], L. GAREAU[3], RUTH RENNER[4] AND L. W. MCELROY[5]

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ABSTRACT

In sulphur-deficient grey wooded soils, fertilizers have caused changes in the protein and mineral composition of legume hay, and have affected nutritive values, besides producing yield increases of up to 500 per cent. Where sulphur-supplying fertilizers were used, the sulphur content of the hay was usually increased and, in some cases, this was true of the protein content as well even where no nitrogen was supplied with the sulphur. Rabbits fed fodder from fertilized plots made faster gains than those fed feeds from unfertilized plots. Where feed efficiency was measured, it was lowest for hay from untreated areas. There were no consistent correlations between chemical composition of the feeds and the marked differences in their nutritive values as measured by rate and efficiency of rabbit gains.

INTRODUCTION

There is considerable analytical evidence which suggests that the use of fertilizers improves the nutritive value of legume hays grown on sulphur-deficient grey wooded soils. Kenwood (7) and Bentley *et al.* (4) have reported that sulphur-supplying fertilizers increase the sulphur and protein content of hays grown on these soils. Wyatt (15) and Newton *et al.* (10) have shown that the protein content of grains following sulphur-fertilized hays is increased. Renner *et al.* (12) found that the higher protein content of such grain was also accompanied by an increased proportion of nine essential amino acids.

Fertilizer use is commonly dependent upon obtaining profitable yield increases. Numerous yield data show that suitable sulphur-supplying fertilizers may increase legume hay yields 100 to 500 per cent on sulphur-deficient grey soil in Alberta (10). However, in other regions there is much evidence that fertilizers have other important effects on forage crops. Nowosad (11) refers to fertilization changing the botanical composition of grass-legume mixtures. Matrone *et al.* (8) and many others report changes

[1]Contribution from Department of Soil Science and Department of Animal Science, University of Alberta.
[2]Professor of Soil Science, University of Alberta.
[3]District Agriculturist, Bonnyville, Alberta (former graduate student).
[4]Former research associate; now research assistant, Cornell University.
[5]Professor of Animal Science, University of Alberta.

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FIGURE 1. Preferential grazing following fertilization with 16—20—0 at 150 lb. per acre. Unfertilized plants *on the left* matured due to lack of grazing there. (Department of Animal Science, University of Alberta, August, 1953).

in the mineral content of hay crops due to fertilization. These changes involve not only the element supplied by a fertilizer but also other mineral elements in the plant material. Alway and Nesom (2) discuss the effects of fertilizers on rate of maturity of hay plants. Hay fertilization has also resulted in palatability differences. One of the most striking examples is reported by Albrecht (1), who describes how a single application of fertilizer produced palatability differences which lasted eight years.

In Alberta, experience of farmers has frequently suggested that the use of fertilizers results in palatability differences in the crops grown. Numerous verbal and some written reports from farmers mention preferential grazing of fertilized areas or a preference for straw coming from fertilized portions of fields. Figure 1 illustrates how sharp such preferential grazing may be.

Fertilizers have sometimes caused important changes in nutritive values of forage crops. Black *et al.* (5) report wide differences in livestock gains and calf weights from phosphate fertilization of range. Smith and Albrecht (14) report both increased and decreased nutritive values of hays as a result of fertilization. Phosphorus and calcium applied to deficient soils produced hay more nutritious to lambs while excess applications of nitrogen and lime had adverse effects on nutritive values. The nutritive differences found would not have been expected on the basis of the chemical data for the feeds used.

There are important economic implications related to the foregoing effects of fertilizers on the composition and nutritive value of hays. This study was undertaken to determine the relative feed value of variously

fertilized legume hays grown on sulphur-deficient soil, as measured by rate and efficiency of gain of rabbits, and to determine whether any differences found are related to the composition of the hays as determined by chemical analyses.

SOURCES OF EXPERIMENTAL FEEDS

The experimental feeds were obtained from various types of fertilizer plots at widely separated geographical locations. These were: Breton Plots operated by the University of Alberta near the town of Breton; the Athabasca Sub-Station of the Canada Department of Agriculture; and a farm field near Vilna in north eastern Alberta. Plots at Breton and Athabasca are each about 1/10 acre in size and are systematically arranged. However, at Breton the check samples were obtained from two separate plots in close proximity to the plots from which the other treatments were obtained. At Vilna each plot was 40 feet by 40 feet. The treatments there were replicated four times in a randomized block design. The experimental feeds consisted of portions taken from each replicate of each treatment. All soils were sulphur-deficient grey wooded ones developed on glacial till. Breton loam is the only one of these soils which has been classified by the Alberta Soil Survey.

Yield data given in Tables 1 and 3 for Breton and Athabasca are the long-term averages for these plots, being 25 years for Breton and 5 years for Athabasca. The Breton data are for the average yield of first- and second-year legume stands. At the other location yields are for one cutting after a single fertilizer application made two or three months prior to harvest.

ANALYTICAL METHODS

Results of chemical analyses are reported on an oven-dry basis and are the averages of duplicate determinations. Nitrogen was determined by the Kjeldahl-Gunning (3) procedure. Mineral analyses were done after samples of the plant material had been ashed by the nitric and perchloric acid procedure. Sulphur was determined turbidimetrically (4). Sodium and potassium were determined by flame photometry using a Beckman Model DU spectrophotometer and attachments. Calcium and magnesium were determined by a procedure based on titration with ethylenediamine tetracetate ("Versene"). The meta-vanadate procedure was used for phosphorus determination. Crude fibre determinations were by a standard procedure (3).

Botanically pure samples for laboratory analyses were hand-selected at Breton when the feeds for Experiment 6 were harvested. Care was taken to select whole plants of comparable maturity and representative of the average plants in the various treatments. In the other experiments finely ground samples of the materials fed to the rabbits were analysed.

EXPERIMENTAL ANIMALS

All experimental animals were recently weaned and 6-9 weeks old when obtained. After arrival at the laboratory they were fed a commercial rabbit feed and gains were determined for a period of 7 to 10 days.

TABLE 1.—YIELDS AND CHEMICAL COMPOSITION OF FEEDS USED IN EXPERIMENTS 1–3

Fertilizer treatment	Application lb. per acre per year				Yield, tons per acre	Chemical composition						
	N	P_2O_5	K_2O	S		N per cent	P per cent	K per cent	S per cent	Ca per cent	Mg per cent	Crude fibre per cent
Experiment 1. Altaswede clover from Breton Plots, 1950.												
Check	—	—	—	—	0.4	2.00	0.24	2.00	0.08	1.50	0.30	24.6
N P K S	8	10	15	7	2.4	2.08	0.18	1.80	0.14	1.79	0.42	24.0
N S	6	—	—	7	2.3	2.27	0.17	1.66	0.14	1.86	0.39	22.5
Lime + P	—	10	—	—	0.7	2.01	0.26	1.86	0.09	1.69	0.34	22.4
Manure + N P S	40?	30?	40?	15?	2.5	2.13	0.20	2.05	0.12	1.48	0.31	23.4
Experiment 2. Alfalfa from Breton Plots, 1950.												
Check	—	—	—	—	0.4	2.34	0.27	1.68	0.10	2.18	0.26	25.4
N P K S	8	10	15	7	2.4	2.03	0.19	1.64	0.29	2.28	0.29	29.0
N S	6	—	—	7	2.3	2.06	0.18	1.57	0.25	2.37	0.29	27.6
Lime + P	—	10	—	—	0.7	2.49	0.27	1.84	0.12	2.00	0.26	26.4
Manure + N P S	40?	30?	40?	15?	2.5	2.24	0.21	1.96	0.17	2.00	0.21	28.2
Experiment 3. Alfalfa from near Vilna, 1951.												
Check	—	—	—	—	0.8	2.35	0.18	1.49	0.10	2.30	0.31	30.7
N S	16	—	—	20	1.9	2.69	0.20	1.52	0.18	2.65	0.38	28.5
Gypsum	—	—	—	20	2.3	2.81	0.18	1.48	0.20	2.52	0.33	30.2
N P S	21	27	—	20	1.7	2.67	0.18	1.36	0.18	2.37	0.36	27.7
Sulphur	—	—	—	20	1.4	2.48	0.21	1.82	0.15	2.38	0.30	28.3
Trace elements[1]	—	—	—	20	2.3	2.69	0.20	1.82	0.19	2.28	0.31	28.5

[1]The trace element mixture consisted of the following: Na_2SO_4, 68 lb.; $MnSO_4$, 20 lb.; $CuSO_4$, $ZnSO_4$, and $Na_2B_4O_7$, 10 lb. each; $Na_2MoO_4.2H_2O$, 0.7 lb.

The animals were then allotted to groups according to litter, sex, weight, and gain during the preliminary period. Initial weight of animals was taken to be the average of their weights for the 3 days prior to commencement of experimental feeding. Similarly, final weight was taken as the average for the last 3 days on experiment. Only water and a small piece of iodized salt were provided in addition to the experimental feed.

The rabbits in Experiments 1 to 3 were housed individually in wooden cages, 18″ × 24″ × 15″ high, with slatted floors, a water-pan and feed-tray. All metal cages, 16″ × 24″ × 14″ high, with wire mesh floors, removable feed-pans and automatic nipple-type waterers were used in Experiments 4 to 6.

RESULTS

The experiments are presented in two parts because of differences in the preparation of feeds and experimental procedures.

I. Experiments with Unpelleted Feeds

Feeds for the first three experiments were from the Breton Plots and a farm near Vilna. The Breton feeds were from an alfalfa-Altaswede clover mixture and were hand-separated to ensure botanical purity. The Vilna alfalfa was obtained by plot-mowing a stand of high botanical purity; the obviously extraneous material was removed by hand. After curing, the Breton hays were processed through a feed cutter set for a 3-inch length and were stored in jute sacks hung in a loft for about 9 months before being used in the feeding trials. The hay from Vilna was processed in the same manner and was fed immediately. The rabbits used were purchased from a different source for each of Experiments 1 to 3. Yield data, chemical analyses of the feeds and results of the feeding trials for these experiments are summarized in Tables 1 and 2.

The feeding trial data are restricted to average daily gains as uncontrollable spillage of feeds made it impossible to obtain feed consumption records. The rate of gain of rabbits within groups was highly variable, probably due in part to lack of uniformity in the animals available. Moreover, feed wastage and the limited initial supply shortened the experimental periods. It is interesting to note that, despite the great variability inherent in these feeding trials, significant differences in rate of gain were observed in Experiment 2. The average rate of gain for the eight groups in Experiments 1 and 2 fed Altaswede clover or alfalfa from fertilized Breton plots was 50 per cent greater than that for groups fed hay from the check plots. For Experiment 3 the corresponding difference was 20 per cent in favour of alfalfa from fertilized plots at Vilna.

The data in Tables 1 and 2 do not demonstrate any consistent relationship between rate of gain and protein, mineral or crude fibre levels in hay or between rate of gain and any given fertilizer treatment. In the second experiment the three feeds from sulphur-fertilized plots are lower in nitrogen than the other feeds in that test; this is contrary to many previous data (4, 7, 13) and is unexplained.

TABLE 2.—RESULTS OF FEEDING TRIALS WITH UNPELLETED FEEDS

Fertilizer treatment	No. of rabbits	No. of days on test	Av. daily gain, gm.
Experiment 1. Altaswede clover from Breton Plots, 1950.			
Check	4	16	12.3
N P K S	4	16	21.8
N S	4	16	22.0
Lime + P	4	16	15.0
Manure + N P S	4	16	16.6
			D. N. S.[1]
Experiment 2. Alfalfa from Breton Plots, 1950.			
Check	4	18	11.4
N P K S	4	18	15.7*
N S	4	18	12.9
Lime + P	4	18	19.1*
Manure + N P S	4	18	20.3*
		M.S.D.[2]	4.0
Experiment 3. Alfalfa from near Vilna, 1951.			
Check	4	21	12.5
N S	4	21	15.7
Gypsum	4	21	14.6
N P S	4	21	14.0
Sulphur	4	21	15.9
Trace elements	4	21	14.8
			D.N.S.

*Denotes statistically significant difference from check (P = 0.05).
[1]Differences not statistically significant.
[2]Minimum difference necessary for statistical significance (P = 0.05).

II. Experiments with Pelleted Feeds

Experiments 4 to 6 were conducted early in 1955 using pelleted feeds. Hand-sorted, botanically-pure Altaswede clover obtained from Breton Plots in 1952 was used in Experiment 4. After curing, the feed was processed through a feed cutter and stored in jute sacks until the fall of 1954. In Experiment 5, Altaswede clover hay mowed from the Sub-Station Plots at Athabasca in 1952 was fed. It was estimated that botanical purity was at least 95 per cent. Other procedures were the same as those of Experiment 4. Altaswede clover of about 98 per cent botanical purity grown in 1954 was used in Experiment 6.

In the fall of 1954, feeds for Experiments 4 to 6 were passed through a combination feed cutter and hammermill with a 3/8″ screen in preparation for pelleting into pellets 7/32″ in diameter. Pelleting was done at a commercial feed plant. Data relating to these experiments are given in Tables 3 and 4.

TABLE 3.—YIELDS AND CHEMICAL COMPOSITION OF FEEDS USED IN EXPERIMENTS 4–6.

Fertilizer treatment	Application lb. per acre per year				Yield, tons per acre	Chemical composition						
	N	P_2O_5	K_2O	S		N per cent	P per cent	K per cent	S per cent	Ca per cent	Mg per cent	Crude fibre per cent
Experiment 4. Altaswede clover from Breton Plots, 1952.												
Check	—	—	—	—	0.4	2.10	0.27	2.42	0.10	1.65	0.29	24.6
N P K S*	17	13	15	7	2.4	2.89	0.27	2.17	0.17	1.60	0.32	23.7
*This feed was a composite of materials from three plots: N P K S, N S, and N P S + manure.												
Experiment 5. Altaswede clover from Athabasca, 1952.												
Check	—	—	—	—	0.9	1.90	0.21	1.74	0.08	1.45	0.28	26.1
Sulphur	—	—	—	7	1.6	2.03	0.20	1.68	0.11	1.56	0.34	28.8
N P S	5	7	—	7	1.6	2.09	0.21	1.81	0.10	1.61	0.33	28.9
N P K S	5	7	7	7	1.6	2.20	0.21	1.53	0.14	1.63	0.42	26.4
Experiment 6. Altaswede clover from Breton Plots, 1954.												
Check	—	—	—	—	0.4	1.86	0.22	1.95	0.08	1.45	0.26	29.3
Gypsum	—	—	—	14	1.6	2.35	0.15	2.08	0.14	1.63	0.30	30.3
P S	—	10	—	5	2.2	2.58	0.27	2.33	0.14	1.63	0.35	29.1
N P	3	10	—	—	0.6	2.19	0.27	2.48	0.10	1.59	0.26	28.7

TABLE 4.—RESULTS OF FEEDING TRIALS WITH PELLETED ALTASWEDE CLOVER FEEDS

Experiment number Location and hay year	4 Breton (1952)		5A Athabasca (1952)				5B Athabasca (1952)				6 Breton (1954)			
Fertilizer treatments	Check	NPKS	Check	S	NPS	NPKS	Check	S	NPS	NPKS	Check	Gyp.	PS	NP
Number of rabbits	4	4	4	4	3[1]	4	3	2	2	2	3	3	3	3
Mean initial weight, gm.	1811	1854	1737	1794	1762	[1]1592	1817	1615	1870	1505	1775	1660	1740	1827
Mean final weight, gm.	1983	2111	1937	2139	2194	2077	1953	1910	2173	1913	2172	2163	2317	2350
Number of days on test	15	15	19	19	19	19	15	15	15	15	31	31	31	31
Mean daily gain, gm.	11.5	17.1*	10.5	18.1*	22.7*	25.5*	9.1	19.7*	20.2*	27.2*	12.8	16.2	18.6	16.9
Mean daily feed, gm.	186	192	128	152	191	156	155	185	164	234	138	222	160	206
Feed per gram gain, gm.	16.2	11.2	12.2	8.4	8.4	6.1	17.0	9.4	8.1	8.6	10.8	13.7[2]	8.6	12.2[2]
M.S.D[3]. for daily gains, gm.	3.3	—	4.0	—	—	—	7.3	—	—	—	D.N.S.[4]	—	—	—

*Denotes statistically significant difference from check (P = 0.05).

[1]Four rabbits placed on test; one died.

[2]Feed wastage was very high.

[3]Minimum difference necessary for statistical significance (P = 0.05).

[4]Differences not statistically significant.

The use of pelleted feeds in Experiments 4 to 6 enabled obtaining more accurate feed consumption records and the experimental animals were more uniform than in the first three trials. An attempt was made to obtain precise feed consumption records but this was not entirely successful. Some animals persistently spilled feed which was often so mixed with urine, feces, and shavings that it was impossible to do other than estimate the weight of wasted feed. Thus, although the data for feed efficiency in Table 4 are reasonable approximations, the records are not considered worthy of statistical treatment.

Statistically significant differences for rates of gain were obtained in Experiment 4. Rabbits fed Altaswede clover hay grown on Breton Plots fertilized with NPKS gained faster than those fed hay from unfertilized plots. Moreover, the feed efficiency for hay from fertilized plots was substantially higher; animals fed hay from unfertilized plots required 45 per cent more feed per unit of gain. These results are in agreement with those obtained in Experiment 1 for Altaswede clover grown at Breton in 1950 under the same fertilizer treatment.

Data for Experiment 5 are summarized under 5A and 5B in Table 4. Part A of this experiment was terminated after 19 days to retain sufficient of the test hays for a palatability test and for a duplicate feeding trial which was conducted two months later. Feed exhaustion terminated feeding test 5B. In both feeding trials, animals fed hay from plots fertilized with S, NPS or NPKS gained at a significantly faster rate than those fed hay from unfertilized plots. Significant differences were obtained with only 2 rabbits per group in Experiment 5B. The average weight of feed required to produce 1 gm. gain was 14.3 gm. for the 7 rabbits fed hay from check plots, as compared to 8.0 gm. for the 17 rabbits fed hay from fertilized plots.

The reliability of the results for Experiment 6 is limited by the fact that it was possible to feed only 3 test animals on each hay and by the fact that feed wastage was exceptionally high. Rabbits fed hay from fertilized plots averaged 35 per cent faster gains than those receiving hay from unfertilized plots. The increase in rate of growth obtained with feed from fertilized plots in this experiment is less than that observed in Experiments 1, 2, and 4 with Breton feeds but is still substantial. It may be noted that animals receiving feed from unfertilized plots made slowest gains in all six experiments.

As in Experiments 1 to 3, the data for Experiments 4 to 6 do not show any clear relationship between rate of gain and protein, mineral or crude fibre levels in hays. The hays from check plots in Experiments 4 to 6 were consistently lower in nitrogen and sulphur content than comparable hays from fertilized plots. However, the possible significance of this is considerably reduced by the fact that rabbits in Experiment 4, fed hay from check plots containing 2.1 per cent N and 0.10 per cent S, made appreciably less rapid gains than did those fed hay of comparable nitrogen and sulphur content in the 'S' and 'NP' groups of Experiments 5 and 6.

Palatability Test

After the growth data were obtained in Experiment 5A, palatability tests were conducted with the feeds. Four rabbits of the same sex were placed in a cage, 36″ × 48″ × 24″, and were allowed to feed ad libitum from two bowls of each feed placed at random each day in different positions in the cage. Weights of feed consumed were recorded over a period of 6 days. The results were striking and unexpected. The amounts consumed were 1,065, 210, 220, and 1,720 grams for hays from the check, S, NPS, and NPKS treatments respectively. These very limited observations suggest that rabbits may not necessarily select the most nutritious feeds when given free choice.

GENERAL DISCUSSION

Although the results of hay feeding trials conducted with rabbits may not provide an accurate estimate of the relative value of hays for ruminants (6, 8, 9), rabbits are very convenient and useful pilot-test animals for experiments of the type reported here. They make rapid gains, and this fact enables differences between feeds to be demonstrated in 2 to 4 weeks, with as little as 10 lb. of feed per animal.

No adequate explanation of the superior nutritive value of the fertilized feeds used in these experiments is possible from the data reported. There is a general tendency for higher nitrogen content in fertilized feed. This is usually related to sulphur application and is in agreement with data reported elsewhere (4, 13). However, there is no close relationship between mineral analyses of the feeds and their nutritive values. Data reported for chemical composition are in general agreement with other analytical results for plant materials grown on the same or similar soil (4, 7).

Changes in the mineral and nitrogen content of plant material as a result of fertilization suggest the possibility of changes in quality as well as in amount of some organic constituents of plants. For example, sulphur fertilization has increased the proportions of certain essential amino acids in the protein of grains grown after legumes on the Breton Plots (12).

The results reported have important practical implications. In evaluating the returns from the use of fertilizers on sulphur-deficient grey soils, farmers need to consider the improved nutritive value as well as the yield increases. These experiments have demonstrated improvements in nutritive values of legume hays as a result of fertilization. More experiments are needed to provide an explanation for, and to determine the range and average degree of nutritive improvement resulting from, such fertilization.

It is the opinion of the authors that the data reported may not exaggerate benefits which farmers on sulphur-deficient soils may obtain from fertilization of forage crops. Sulphur fertilization has increased protein content of a legume by as much as 46 per cent. In addition, sulphur fertilization frequently causes marked changes in botanical composition of grass-legume mixtures by increasing the proportion of legume.

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INFLUENCE OF THE MATERNAL PARENT ON THE YIELD OF FLINT × DENT DOUBLE-CROSS CORN HYBRIDS[1]

F. Dimmock and L. S. Donovan

Canada Department of Agriculture, Ottawa

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ABSTRACT

Four reciprocal double-cross corn hybrids were produced by using flint and dent single crosses as maternal parents.

Yield tests indicated no advantage for either flint or dent when used as the seed parent in any of the reciprocals.

Considering the four hybrids as a group, there was a significant increase in yield in favour of dent seed parentage in 1952, but no differences in 1951.

INTRODUCTION

The acreage of corn for grain production has increased greatly in Canada during recent years. Much of this increase has resulted from expansion into new areas by the use of early maturing hybrids which have been made available through breeding research programs. Some of these early hybrids combine flint type inbreds with inbreds of the dent type. The usual practice has been to hybridize single crosses consisting of either flint or dent lines, thus endeavouring to combine the early maturity of the flints with the higher yielding capacity and more desirable plant type of the dents in the resultant hybrid.

The object of this investigation was to study the influence of the maternal or seed parent on yield.

MATERIALS AND METHODS

Five flint corn inbreds, 32, 39, 42, 62 and 226, and three dent corn inbreds, 179, 190 and 221, were combined in four double-cross hybrids. While three of the flint inbreds, 32, 39 and 42, were related, none of the related lines was used in the same single cross. All three dent inbreds originated from different sources.

The double crosses were made up as follows: (42 × 62) (179 × 221), (226 × 39) (179 × 190), (32 × 226) (190 × 221),(226 × 42) (179 × 221). Seed of the reciprocals was produced by using each single cross as male and female parents.

In 1951 and 1952 the four reciprocals were tested at Ottawa in a randomized block arrangement with four replications. Each replicate comprised a single row of 16 hills, with 3 plants per hill. The row and hills were 3 feet apart. At harvest time the two end hills from each row were discarded and the ears from the remaining fourteen hills harvested for yield data. They were dried to approximately 10 to 12 per cent of moisture in a forced air drier, then shelled, and the moisture content of the shelled corn determined in an Electric Moisture Tester. The yields were calculated on the basis of dry matter.

[1]Contribution from the Forage Crops Division, Experimental Farms Service.

EXPERIMENTAL RESULTS

Yield data from each of the two years' plantings were analysed statistically in two ways: First, as coming from a split-plot randomized block design with hybrids as main plots and seed parents as sub-plots; and second, the single degree of freedom method was used on the data as coming from a single randomized block design. The first method was used to obtain an evaluation of seed parent effects over all hybrids, and the second to provide a precise measurement of the same effects within each of the four hybrids.

A summary of the split-plot analysis of the 1951 data is given in Table 1 and indicates no influence of seed parent on yield. The difference between seed parents on yield within No. 3 hybrid was sufficient to give a significant parents × hybrids interaction in the analysis. Therefore, the single degree of freedom method was followed, even though seed parent effects in the other three hybrids were obviously nil. Results from this analysis showed, however, that there was no significant difference due to seed parent within hybrid No. 3.

TABLE 1.—INFLUENCE OF THE SINGLE-CROSS SEED PARENT ON THE YIELD OF FOUR DENT X FLINT DOUBLE-CROSS HYBRIDS, 1951

Hybrid	Av. yield, bu. per acre Seed parent	
	Dent	Flint
1. (179 × 190)		
(226 × 39)	61.4	61.0
2. (179 × 221)		
(226 × 42)	57.1	57.1
3. (179 × 221)		
(42 × 62)	56.1	58.9
4. (190 × 221)		
(32 × 226)	56.3	56.3
Seed parent means	57.7	58.3

Corn yields in 1951 were low, due chiefly to a period of drought in mid-summer and generally cool temperatures. Conditions were better in 1952, and hence that year's data are considered to give a more accurate evaluation of seed parent influences. Examination of the split-plot analysis of the 1952 data, Table 2, shows that, over the four hybrids, dent seed parentage was conducive to higher yields. The influence was quite variable among hybrids as evidenced by the highly significant parents' × hybrids' interaction which was obtained. However, the single degree of freedom method of analysis showed that, within any one hybrid, seed parentage had no effect on yield.

DISCUSSION

In the production of a flint × dent double-cross hybrid it is important to know whether the single-cross used as the maternal or seed parent has any influence upon the double cross yield.

TABLE 2.—INFLUENCE OF THE SINGLE-CROSS SEED PARENT ON THE YIELD OF FOUR DENT X FLINT DOUBLE-CROSS HYBRIDS, 1952

Hybrid	Av. yield, bu. per acre Seed parent	
	Dent	Flint
1. (179 × 190) (226 × 39)	82.2	80.9
2. (179 × 221) (226 × 42)	80.0	75.3
3. (179 × 221) (42 × 62)	76.8	76.0
4. (190 × 221) (32 × 226)	77.9	72.9
Seed parent means	79.2	76.3
L.S.D. for seed parents at 5% level		2.5

From the seed production standpoint, the commercial producer prefers to use the dent single cross as the maternal parent because the yield of seed is higher, grades better and has a more attractive appearance than the flint. It can be seeded with greater precision with modern machinery, because of its shape. While these are important considerations they disregard any influence which the method of combination may have on ultimate yield.

Strommen* tested reciprocals of a flint × dent double cross and found no significant difference in the yield of grain. Raymond** conducted silage tests at three locations with reciprocals of Algonquin, a varietal hybrid between Quebec No. 28 (flint) and Wisconsin No. 7 (dent). The results showed no significant difference between them when yields of dry matter were compared.

Genotypically, the embryo of reciprocals is the same. The only difference is the pericarp, which is entirely maternal tissue, and the endosperm, which receives a double contribution from the female parent at fertilization. It is conceivable that the difference between the endosperm tissue of a flint and a dent could to some extent influence the behaviour of the reciprocals, although such influence would be expected to occur during germination and the early seedling stage, while the endosperm is being expended. Whatever this influence may be, the tests reported here indicate that they are small, with the possibility of there being some increase in yield where the dent is used as the seed parent. Therefore, considering the additional advantages of dent seed-parentage, it is suggested that the dent single cross be used as the maternal parent in the production of flint × dent double-cross hybrids.

*Strommen, A. M. Agr. Expt. Station, Spooner, Wis. (*Unpublished data*).
**Raymond, L. C. Agronomy Dept., Macdonald College, Que. (*Unpublished data*).

BREEDING APPLES FOR RESISTANCE TO SCAB[1]

L. P. S. Spangelo[2], J. B. Julien[3], H. N. Racicot[3] and D. S. Blair[2]

Canada Department of Agriculture, Ottawa

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ABSTRACT

The scab resistance of several small-fruited *Malus* selections has been transmitted to the progeny of crosses with commercial varieties. Scab-resistant seedlings also resistant to powdery mildew have been selected. It appears possible to develop commercial varieties resistant to both diseases by back-crossing.

INTRODUCTION

Scab caused by (*Venturia inaequalis* (Cke.) Wint.) is the most widely distributed and destructive disease of the apple in Canada. This disease is present in all commercial apple-growing areas and is a particularly serious threat to the industry in the eastern provinces. McIntosh, the most important commercial apple in Canada, is highly susceptible. Although certain large-fruited varieties are less susceptible than many others, all commercially desirable varieties require fungicide sprays for scab control.

It is difficult to determine accurately the annual losses to Canadian growers caused by this disease. However, severe blossom infection can result in a complete loss of crop and a heavy foliage infection may defoliate the trees. Scab lesions on the fruits affect their commercial grade, cause shrivelling, and permit the entrance of rot-producing fungi. Depending on the number of scab infection periods, a grower in eastern Canada might spray his orchard eight to ten times in a single season to prevent these losses.

In 1934, Rudloff and Schmidt (7) reported that under conditions of natural field infection in Germany selections of *Malus coronaria*, *M. toringo*, *M. atropurpurea* and *M. micromalus* were resistant to apple scab. Hockey and Eidt (2) reported on the scab susceptibility of several standard varieties and the progenies of over 100 crosses under field infection at Kentville, Nova Scotia. They suggested the possibility of obtaining resistant progenies from crosses with Yellow Transparent. Hough (3) reported that *M. floribunda* was the most resistant parent of several apple species studied. More recently, Shay and Hough (8, 9) and Hough and Shay (4), Hough, Shay and Dayton (5), Shay, Dayton and Hough (11) and Dayton, Shay and Hough (1) published progress reports on breeding scab-resistant commercial varieties in the United States. In 1952, Shay and Hough (10) stated that 30 species and varieties of the genus *Malus* had shown a high degree of resistance in the field and in controlled infection tests.

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[1]Joint contribution from the Horticulture Division, Experimental Farms Service, (Contribution No. 839), and the Botany and Plant Pathology Division, Science Service, (Contribution No. 1535).

[2]Horticulturist, and Principal Horticulturist (Fruits), respectively, Horticulture Division, Experimental Farms Service.

[3]Assistant Plant Pathologist, and Plant Pathologist, respectively, Botany and Plant Pathology Division, Science Service, Ottawa.

To determine the possibilities of incorporating resistance into commercial varieties, a co-operative project between the Horticulture Division, Experimental Farms Service, and the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario, was established in 1949. The Horticulture Division has been responsible for the collection and evaluation of parental material, making the crosses, and growing and evaluating the seedlings. The Botany and Plant Pathology Division has been responsible for the preparation of the inoculum and for all studies on the organism, and has assisted in evaluating the susceptibility of the seedlings.

METHOD OF ELIMINATING THE SUSCEPTIBLE SEEDLINGS

The crosses are made in the orchard. As soon as the fruit is harvested in the fall, the seeds are extracted and sown in flats. The flats are then placed in storage at 38°F. for the stratification period, and in late December they are removed to the greenhouse for seed germination. Seedlings are first inoculated when the majority are at the first and second true-leaf stage. The inoculum is a mixture of conidia from a number of isolates of the fungus obtained from several areas in Canada. The water suspension of conidia, approximately 100 per microscope field (100X), is sprayed on the foliage, and the inoculated plants are held in a moist chamber for 48 hours at 68°F.

Symptoms usually appear 2-3 weeks after inoculation. The susceptible seedlings are discarded and the remainder are inoculated again. This procedure is repeated at least three times during the winter. In the spring the resistant seedlings are planted in outdoor seed beds. The following spring they are moved to nursery rows and a year later to their field location for fruit testing. Final selection of scab-resistant seedlings is therefore determined under conditions of natural field infection. Certain seedlings have also been planted for tree and fruit evaluation at the Experimental Farm, Kentville, Nova Scotia, to determine their reaction to other physiological races of the fungus that may occur there.

Five infection classes are used to facilitate the roguing of susceptible seedlings:

I. No evidence of infection.
II. Pin-point depressions with no sporulation.
III. Irregular, necrotic, chlorotic or depressed lesions with no sporulation.
IV. Lesions few, elongated or irregular, necrotic or chlorotic, with sparse sporulation.
V. Stem lesions or leaf lesions, necrotic or chlorotic, elongated or irregular, sporulating freely.

Because of lack of sporulation, seedlings in Classes I, II and III, are considered highly resistant.

VARIABILITY OF THE SCAB ORGANISM

The fungus is an ascomycete and its apparent ability to develop new strains may complicate breeding for resistance. McCrory and Shay (6) reported that in Indiana the variety Alexis exhibited a high degree of resistance under controlled and field conditions and developed necrotic non-sporulating lesions only. On the other hand, Alexis is susceptible, under controlled conditions, at Ottawa, and McCrory and Shay (6) re-

ported that Alexis is susceptible in South Dakota. Apparently, therefore, the isolates used for the inoculations at Ottawa and Purdue University differ in pathogenicity, and certain races of the fungus capable of infecting Alexis are present in Canada and South Dakota but absent in Indiana.

A uniform collection of trees, representing several identifiable resistant genotypes, is being grown in Nova Scotia, Quebec and Ontario. In this way it should be possible to sample quickly the existing physiological races of scab in eastern Canada.

BREEDING METHOD

Varieties and seedlings are tested under controlled conditions in the search for resistant parents. When these are found, the most desirable genes for resistance are incorporated into good fruit types in a backcross program.

The two Divisions work closely with J. R. Shay, Department of Botany and Plant Pathology, Purdue University, Lafayette, Indiana, co-ordinator of the co-operative project at the Universities of Purdue, Rutgers and Illinois. Sources of resistance established by Shay *et al.* are being included in the program at Ottawa.

In the spring of 1949, 50 seedlings of Wolf River × R12740-7A (*Malus pumila*) parentage and 100 seedlings of the parentage Jonathan × 26829-2-2 ((Rome Beauty × *M. floribunda*) sib) were obtained from Shay and planted for fruiting at Ottawa and at the Horticultural Substation, Smithfield, Ontario, respectively. The trees have never been sprayed with a fungicide and only a few have developed thinly scattered restricted sporulating lesions. The fruit appearance of most of the seedlings that fruited at Smithfield is commercially satisfactory; eating quality ranges from poor to medium and fruit diameter from $1\frac{1}{2}$ to $2\frac{5}{8}$ inches. The best of these seedlings have been used in backcrosses to commercial varieties.

RESULTS OF CROSSING AND SEEDLING EVALUATION AT OTTAWA

Geneva (*Malus pumila* var. *Niedzwetzkyana* open-pollinated) was the main source of resistance in the first crosses made at Ottawa in the spring of 1949. Geneva was crossed with the commercial varieties Atlas, Close, Crimson Beauty, McIntosh and Melba. Duchess has shown a limited resistance and a few seedlings of Duchess × McIntosh were tested. Out of a total of 1333 seedlings inoculated in 1950, 148 were resistant.

By 1951, a race of the fungus capable of infecting the Geneva variety was found in both the Ottawa, Ontario, and Kentville, Nova Scotia, areas. A tissue isolate from infected Geneva trees at the Kentville Experimental Farm was used for inoculating 197 Geneva open-pollinated seedlings at Ottawa. Of these, 6 showed no sporulation, 7 developed restricted sporulating lesions and the others had freely sporulating lesions. Ten of the 13 seedlings have not developed sporulating lesions under field conditions. Within this group selection of segregates for continued breeding should be possible.

Since 1949 the main sources of resistance have been R12740-7A, a selection of *Malus pumila*, and selections from the crosses Jonathan × ((Rome Beauty × *M. floribunda*) sib), Wolf River × *M. atrosanguinea*, Wolf River × *M. prunifolia* and Wealthy × *M. prunifolia*.

TABLE 1.—PARENTAGE OF 1950 CROSSES AND RESULTS OF INOCULATIONS

Parentage	Seedlings inoculated	Per cent in classes I, II, III
Cortland × 26829-2-1	14	0
Melba × 26829-2-1	112	0
Antonovka × 26829-2-1	250	4
Antonovka × R12740-7A	327	7
Petrel × R12740-7A	328	8
Cortland × R12740-7A	28	11
Melba × R12740-7A	98	3
Melba × Petrel and reciprocal	1293	0
Petrel × Antonovka	257	0

Table 1 shows the parentage of the 1950 crosses and results of the seedling inoculations.

The scab-resistant parents in Tables 1 to 8 have the following parental background:

26829-2-1, 26829-2-2 and 26830-2: (Rome Beauty × *M. floribunda*) sib
R12740-7A: *Malus pumila* selection
R6 T68, R18 T40: Jonathan × 26830-2
R6 T116, Dg 20-3, Dg 20-9, Dg 22-81, 47-108E, 49-121E: Jonathan × 26829-2-2
R7 T19, R7 T23, R7 T25, R7 T41, R7 T45: Golden Delicious × 26829-2-2
R13 T52: Wolf River × *M. prunifolia* 19651
R14 T43, R14 T60, R15 T53: R12740-7A × Wealthy
R16 T19, R16 T52: Wolf River × *M. atrosanguinea* 804
R25 T75: Wealthy × *M. prunifolia* 19651
49-36-01, 49-36-35: Wolf River × R12740-7A.

All Smithfield selections listed in Table 3 are of Jonathan × 26829-2-2 parentage.

Antonovka and Petrel are less susceptible to scab than Melba. As indicated in Table 1, Antonovka crossed with 26829-2-1 produced a higher percentage of seedlings in Classes I, II and III than Melba crossed with the same resistant parent. Antonovka and Petrel produced a higher percentage of resistant seedlings than Melba, when crossed with R12740-7A. Similarly, Cortland appeared superior but the progeny size was very small. Petrel was of no value as a parent for resistance when crossed with Melba or Antonovka. Sixty-eight seedlings that developed lesions with restricted sporulation (Class IV) were saved to determine their reaction to scab under field conditions.

Since commercial varieties in Canada are susceptible to scab, no great degree of resistance is possible in the progenies of any crosses between them. However, some seedlings from such crosses are less susceptible than others. In 1952, 9616 seedlings from crosses between the susceptible varieties Astrachan, Bancroft, Close, Cortland, Fameuse, Hume, Lawfam, McIntosh, Melba, Newtosh, Sandow and Spartan, were inoculated in outdoor seedbeds and cold frames. The most susceptible seedlings were discarded, and several of the 1257 retained had restricted sporulating lesions, but these were held to determine their reaction to scab under field conditions.

TABLE 2.—PARENTAGE OF 1952 CROSSES AND RESULTS OF INOCULATIONS

Parentage	Seedlings inoculated	Per cent in classes I, II, III
Red Melba[1] × R6 T68	102	19
Melba × R6 T68	567	21
McIntosh × R6 T68	33	18
Red Melba[1] × R16 T19	1122	32
Melba × R16 T19	468	28
McIntosh × R16 T19	255	32
Red Melba[1] × R16 T52	950	32
McIntosh × R16 T52	29	24
McIntosh × R7 T19	12	8
McIntosh × R13 T52	27	26
(Jonathan × 26829-2-2-) o.p.[2]	4	50

[1]Platt's strain.
[2]Open-pollinated.

TABLE 3.—PARENTAGE OF 1953 CROSSES AND RESULTS OF INOCULATIONS

Parentage	Seedlings inoculated	Per cent in classes I, II, III
McIntosh × R6 T116	186	20
McIntosh × R7 T23	202	2
McIntosh × R7 T41	52	4
McIntosh × R7 T45	226	2
McIntosh × R14 T43	34	50
McIntosh × R14 T60	360	49
McIntosh × R15 T53	385	8
McIntosh × R18 T40	243	31
McIntosh × R25 T75	35	40
49-36-01, o.p.	19	42
R47 T108, Smithfield, o.p.	27	37
R47 T116, Smithfield, o.p.	25	44
R47 T118, Smithfield, o.p.	17	53
R48 T118, Smithfield, o.p.	32	56
R48 T120, Smithfield, o.p.	27	44
R48 T122, Smithfield, o.p.	70	47
R49 T117, Smithfield, o.p.	233	33

Table 2 shows the parentage of the 1952 crosses of resistant with susceptible varieties and results of the inoculations.

All seedlings that developed sporulating lesions were discarded and 1094 were saved. McIntosh, Melba and Red Melba differed little as parents in crosses with R6 T68 and R16 T19.

Table 3 records data on the 1953 crosses.

In addition to 542 seedlings in Classes I, II and III, 85 in Class IV were saved for a fruiting test. Seedlings R14 T43, R14 T60 and R15 T53 have a common parentage but it is obvious that R15 T53 was the least desirable parent in crosses with McIntosh.

TABLE 4.—PARENTAGE OF 1954 CROSSES AND RESULTS OF INOCULATIONS

Parentage	Seedlings inoculated	Per cent in classes I, II, III
McIntosh × Dg 20-3	338	10
McIntosh × Dg 20-9	320	18
McIntosh × Dg 22-81	1256	10
McIntosh × R7 T19	380	9
McIntosh × R7 T25	1340	9
47-108E × McIntosh	184	31
49-121E × McIntosh	59	22
49-36-35 × McIntosh	302	7

Table 4 shows the results of inoculations of seedlings from the 1954 crosses.

Seedlings Dg 20-3, Dg 20-9, Dg 22-81, 47-108E and 49-121E have a common parentage. As a resistant parent, seedling 47-108E was superior to the other four in crosses with McIntosh.

Apparently resistant seedlings selected as parents from certain progenies differ in their combining ability for the I, II and III type of resistance. This suggests that modifying factors for resistance may be

TABLE 5.—COMBINED RESULTS OF 1953, 1954 AND 1955 INOCULATIONS OF CERTAIN PROGENIES

Parentage	Seedlings inoculated	Year inoculated	Seedlings in classes I, II, III
McIntosh × R7 T19	12	1953	1
McIntosh × R7 T23	202	1954	4
McIntosh × R7 T41	52	1954	2
McIntosh × R7 T45	226	1954	5
McIntosh × R7 T19	380	1955	33
McIntosh × R7 T25	1340	1955	124
	2212		169

TABLE 6.—COMBINED RESULTS OF 1954 AND 1955 INOCULATIONS OF CERTAIN PROGENIES

Parentage	Seedlings inoculated	Year inoculated	Seedlings in classes I, II, III
McIntosh × R6 T116	186	1954	37
McIntosh × Dg 20-3	338	1955	33
McIntosh × Dg 20-9	320	1955	57
McIntosh × Dg 22-81	1256	1955	128
47-108E × McIntosh	184	1955	57
49-121E × McIntosh	59	1955	13
	2343		325

contributed by a susceptible parent. The progeny sizes in the foregoing tables are in some cases rather small. By grouping the data from Tables 2, 3 and 4, further evidence to support this hypothesis seems apparent. These data are presented in Tables 5 and 6.

McIntosh is the common and susceptible parent in all crosses in Tables 5 and 6, but in Table 5 the source of resistance is Golden Delicious × 26829-2-2, while in Table 6 it is Jonathan × 26829-2-2. With Jonathan ×26829-2-2 as the source of resistance, 14 per cent of the seedlings were resistant; with Golden Delicious × 26829-2-2 as the resistant parent, only 8 per cent were resistant.

INHERITANCE OF RESISTANCE

Progeny data recorded by Hough, Shay and Dayton (5) suggest that the original *M. floribunda* clone is heterozygous for a single dominant gene for resistance. Some seedlings homozygous or heterozygous for this gene may develop sporulating lesions when inoculated under severe controlled conditions but are resistant in the field. Classification of such seedlings as resistant segregated the resistant and susceptible in a 1 : 1 ratio. Insufficient data have been recorded to determine the inheritance of resistance, but if all seedlings that developed restricted sporulating lesions (Class IV) are classified as resistant, the Ottawa data support the findings of Hough, Shay and Dayton (5). Grouping the data from the 1950, 1952, 1953 and 1954 crosses of various susceptible varieties with several seedlings with the *M. floribunda* type of resistance places 51 per cent of 5162 inoculated seedlings in Classes I, II, III and IV. Only 11 per cent of the seedlings were in Classes I, II and III.

Grouping the data from crosses of susceptible parents with selections from four sources of resistance, Table 7 shows that the percentage of seedlings in Classes I, II and III from resistant selections of *M. atrosanguinea* was higher than from R12740-7A and selections of *M. floribunda*. Similarly selections of *M. prunifolia* appeared superior but the number of seedlings of this parentage inoculated was very small.

TABLE 7.—SUMMARY OF RESULTS OF CROSSES OF SUSCEPTIBLE PARENTS WITH SELECTIONS FROM FOUR SOURCES OF RESISTANCE

Number of susceptible parents	Specific source of resistance	Number of progenies	Seedlings inoculated	Per cent in classes I, II, III
1[1]	*M. prunifolia*	2	61	34
3[2]	*M. atrosanguinea*	5	2824	31
5[3]	R12740-7A	5	1862	16
5[4]	*M. floribunda*	19	5876	12

[1]McIntosh; [2]McIntosh, Melba, Red Melba; [3]McIntosh, Melba, Cortland, Petrel, Antonovka; [4]McIntosh, Melba, Red Melba, Cortland, Antonovka.

MILDEW SUSCEPTIBILITY OF CERTAIN SCAB RESISTANT SEEDLINGS

Before 1952, powdery mildew (*Podosphaera leucotricha* (E. and E.) Salm.) had been occasionally observed at Ottawa on nursery trees only, not on orchard trees either at Ottawa or the Horticultural Substation,

Smithfield. However, all orchards at both Stations received regular fungicide sprays for control of apple scab until scab-resistant seedlings were transplanted to the field. Whether or not mildew would have appeared on such trees, had the spraying been omitted, is unknown.

Unsprayed scab-resistant seedlings of Wolf River × R12740-7A parentage planted in an orchard at Ottawa in 1949 have not been susceptible to mildew, but other unsprayed scab-resistant seedlings growing in seedbeds and nursery rows have shown a juvenile susceptibility. The close spacing in the seedbeds and nursery and certain other environmental conditions would be conducive to mildew development. Table 8 shows that in the seedbeds at Ottawa in 1952 mildew severely infected 38 seedlings from some of the 1950 crosses.

If juvenile susceptibility is indicative of the adult condition, mildew control on the 38 seedlings in Table 8 would very probably necessitate a spray program as extensive as that for scab control in commercial orchards. Several seedlings from more recent crosses have shown a juvenile susceptibility to mildew at Ottawa.

The Jonathan × 26829-2-2 scab-resistant seedlings planted at the Horticultural Substation, Smithfield, in 1949 were susceptible to mildew during 1952, 1953 and 1954. Since several of these fruited in 1952, this indicates adult susceptibility. Table 9 shows the mildew susceptibility of all the seedlings from 1952 through 1954.

Although each seedling did not develop the same degree of infection each year, the data suggest that all seedlings in the medium, severe and

TABLE 8.—SCAB-RESISTANT APPLE SEEDLINGS FROM 1950 CROSSES WITH SEVERE MILDEW INFECTION

Parentage	Seedlings examined	Severely infected
Melba × R12740-7A	19	4
Petrel × R12740-7A	51	19
Antonovaka × R12740-7A	48	14
Cortland × R12740-7A	4	1

TABLE 9.—MILDEW INFECTION OF SCAB-RESISTANT SEEDLINGS AT THE HORTICULTURAL SUBSTATION, SMITHFIELD

Infection class	Number of seedlings in each infection class		
	1952	1953	1954
No mildew	12	4	1
Trace	11	23	22
Medium	34	32	43
Severe	22	21	20
Very severe	12	11	5

very severe infection classes are highly susceptible to mildew. To control this disease all seedlings in the severe and very severe classes would very obviously require spraying.

A 1953 survey of apple trees in commercial nurseries indicated that mildew is not so prevalent in Quebec as in southwestern Ontario. In this same year, in the area around Strathroy, Ontario, the regular application of fungicides did not completely control mildew on nursery trees, and one nurseryman reported McIntosh and Cortland to be the most susceptible of the varieties grown there.

Powdery mildew susceptibility may be of economic importance in certain regions, of which the Smithfield area is very probably one. The advantages of apple varieties resistant to apple scab are nullified if at the same time they are highly susceptible to mildew.

DISCUSSION AND CONCLUSIONS

Some scab-resistant seedlings of Jonathan × 262829-2-2 parentage, which have fruited at the Horticultural Substation, Smithfield, have fruits that are $2\frac{1}{2}$ inches in diameter. Since the *M. floribunda* scab-resistant parent has fruit less than one-half inch in diameter linkage between scab resistance and small fruit size is not apparent.

The scab-resistant parents have undesirable fruit size and quality, but their resistance has been transmitted in crosses with varieties that bear large fruit of good quality. These scab-resistant seedlings are expected to have improved fruit quality for at Ottawa seedlings of fairly good quality have been developed by using good-quality varieties for backcrossing with seedlings of *M. baccata* × commercial varieties. Selecting and backcrossing two or three times to good-quality varieties should result in resistant segregates with desirable commercial fruit characters. Segregation for such characters within the relatively small group of seedlings in Classes I, II and III should permit the selection of commercial varieties with the most desirable type of scab resistance.

Scab-resistant seedlings from certain progenies differ in their combining ability for the I, II and III type of resistance. Those that are superior as parents for scab resistance may not be the best parents for general tree and fruit characters. This will not be determined until several progenies have fruited but, to make certain that genes for the most desirable general characters are maintained in the crossing program, several selections from each source of resistance are being used as parents.

Since certain scab-resistant selections are also resistant to mildew, susceptibility to mildew is not closely linked with resistance to scab. Therefore, the development of scab-resistant commercial varieties also resistant to mildew appears possible. A commercial variety that does not develop sporulating scab lesions would be very valuable.

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YIELD-OF-NUTRIENT CURVES AND AVAILABILITY OF PHOSPHORUS AND POTASSIUM IN BURFORD LOAM IN THE GREENHOUSE[1]

J. A. Smith[2]

Ontario Agricultural College, Guelph, Ontario

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ABSTRACT

An oat crop followed by a red clover-orchard grass mixture was grown in the greenhouse on a Burford loam soil with increasing rates of added phosphorus and potassium.

Light "starter" applications of phosphorus and potassium placed near the seed were sufficient for maximum yield of oat plants. Yields of hay were increased by additional "soil" treatments of these two nutrients.

The total uptake of phosphorus or potassium increased with each additional increment of these elements except for the "starter" treatment. Close linear relationships were observed between the amounts of phosphorus and potassium removed by cropping and the amounts applied as fertilizer.

Extrapolation of these linear regressions to the points of intersection on the x-axes gave soil "P-values" and "K-values" in terms of the added fertilizer materials. The regression coefficients provided an estimation of the percentage utilization of the fertilizer applied.

The soil was shown to have a considerable capacity to fix added phosphorus and to release non-exchangeable potassium. It is suggested that these two phenomena help to explain the lack of consistent and significant response of this soil to applied phosphorus and potassium in the field.

The relationship between the supply of available soil nutrients, rates of applied fertilizer, and uptake of nutrients by plants has long been the subject of exhaustive research. However, no general principle as yet seems to have been evolved which will fit all, or even most, soils.

The Soils and Agricultural Engineering Farm, located near the Ontario Agricultural College at Guelph, consists mainly of soil of the Burford loam type. Fertilizer experiments carried out on field crops on this farm over the past 5 years have failed to show significant or consistent response to phosphorus. Response to potassium has often been small and, in general, erratic, despite a rather low level of exchangeable potassium as shown by soil tests. Accordingly, a greenhouse experiment was set up with the following objectives:

1. To determine the relationship between the uptake of phosphorus and potassium from this soil and the amounts of these elements applied as fertilizer.

2. To estimate, by means of yield-of-nutrient curves, the available supply of phosphorus and potassium in the soil and percentage utilization of applied fertilizer.

3. To measure the apparent phosphorus-fixing capacity and the potassium-supplying power of the soil.

LITERATURE REVIEW

Recent studies (4, 9, 12) have shown that, over a considerable range of fertilizer application, total nutrient absorption, or yield of nutrient, is essentially a linear function of the rate of application. Dean (4) has

[1]Contribution of Department of Soils, Ontario Agricultural College.
[2]Lecturer, Department of Soils, Ontario Agricultural College.

TABLE 1.—CROP YIELD AND PHOSPHORUS CONTENT AS INFLUENCED BY APPLIED PHOSPHORUS

Treatment number	Treatment[1] (lb./ac. P_2O_5)		Crop yield[2] (gm./pot)					Phosphorus content[2] (% P)				Phosphorus removed[2] (lb./ac. P_2O_5)				
				Red clover-orchard grass					Red clover-orchard grass				Red clover orchard-grass			
	Starter	Soil	Oat plants	1st crop	2nd crop	3rd crop	Total	Oat plants	1st crop	2nd crop	3rd crop	Oat plants	1st crop	2nd crop	3rd crop	Total
1	0	0	2.40	20.8	17.8	20.8	61.8	0.23	0.12	0.18	0.23	3.6	16.6	20.9	31.2	72.3
2	60	0	3.02	22.0	22.3	22.6	69.9	0.26	0.13	0.18	0.23	5.0	18.3	25.8	33.9	83.0
3	60	120	2.80	23.1	28.6	22.4	76.9	0.34	0.16	0.17	0.23	6.1	24.5	32.0	33.0	95.6
4	60	240	3.02	25.6	31.4	22.8	82.8	0.37	0.20	0.19	0.23	7.1	32.4	38.7	33.6	111.8
5	60	480	3.17	26.6	33.2	23.7	86.7	0.43	0.27	0.24	0.26	8.8	46.4	50.0	38.8	144.0
L.S.D.	(0.05)		0.29	2.3	4.0	2.4	10.4	0.02	0.02	0.02	0.010	0.9	4.9	4.6	2.5	14.4
	(0.01)		0.39	3.1	5.5	3.3	14.0	0.03	0.03	0.03	0.014	1.3	6.9	6.5	3.5	19.2

[1]All treatments also received K_2O at 50 lb./ac. as starter treatment and 200 lb./ac. as soil treatment.
[2]Average of 4 replications.

TABLE 2.—CROP YIELD AND POTASSIUM CONTENT AS INFLUENCED BY APPLIED POTASSIUM

Treatment number	Treatment[1] (lb./ac. K_2O)		Crop yield[2] (gm./pot)					Potassium content[2] (% K)				Potassium removed[2] (lb./ac. K_2O)				
				Red clover-orchard grass					Red clover-orchard grass				Red clover orchard-grass			
	Starter	Soil	Oat plants	1st crop	2nd crop	3rd crop	Total	Oat plants	1st crop	2nd crop	3rd crop	Oat plants	1st crop	2nd crop	3rd crop	Total
6	0	0	2.72	18.8	15.8	15.4	52.7	2.66	0.76	0.98	0.96	24	48	51	49	172
7	50	0	3.08	20.4	20.0	16.7	60.2	3.50	0.89	0.77	1.00	36	61	52	55	204
8	50	100	3.13	22.2	25.8	22.2	73.3	4.35	1.14	0.78	0.96	45	84	67	71	267
9	50	200	3.02	25.6	31.4	22.8	82.8	4.79	1.74	0.87	1.05	48	148	91	80	367
10	50	400	2.72	23.6	30.8	24.3	81.4	4.60	2.57	1.23	1.39	42	202	126	113	483
L.S.D.	(0.05)		0.29	2.3	4.0	2.4	10.4	0.22	0.09	0.15	0.12	7	9	11	8	35
	(0.01)		0.39	3.1	5.5	3.3	14.0	0.31	0.13	0.21	0.16	10	13	15	11	47

[1]All treatments also received P_2O_5 at 60 lb./ac. as starter treatment and 240 lb./ac. as soil treatment.
[2]Average of 4 replications.

suggested the use of this linear relationship to estimate nutrient availability in soils. He has demonstrated how yields of phosphorus, as a function of pounds of phosphorus applied, can be extrapolated to intersect the x-axis to the left of the point of origin (zero addition). The amount of phosphorus represented by the distance between the origin and the point of intersection on the x-axis is postulated as being a measure of the original phosphorus in the soil with an availability equal to the fertilizer phosphorus and expressed in the same units. He found that soil phosphorus values estimated by this means did not differ significantly from the "A-values" of Fried and Dean (5), which purport to measure the same thing using the radioactive tracer technique. Dean (4) also showed the soil phosphorus values obtained by extrapolation to be independent of the crop used.

Munson and Standford (9) found that the relation between total nitrogen uptake and the level of applied nitrogen was linear for all soils studied. Extrapolation of the yield-of-nitrogen curves provided available soil "N-values" which correlated highly both with the total nitrogen uptake from the check pots and with nitrate nitrogen production during a 2-week period of incubation.

These results suggest that this concept might be extended to other plant nutrients as well. It offers interesting possibilities in the field of soil fertility since the plant itself is used to measure the supply of available nutrients in the soil.

MATERIALS AND METHODS

Burford loam has been described by Gillespie and Richards (6). This soil has developed on well-sorted gravelly calcareous materials. The topography is nearly level, but the open gravelly parent materials provide rapid internal drainage and in dry periods the soil is quite droughty. In general, Burford soils have a rather low natural fertility. The reaction is about neutral.

Soil tests have shown the Burford loam on the S. and A.E. Farm to be relatively high in chemically extractable phosphorus but fairly low in exchangeable potassium. A quantity of this soil from the surface 6 inches was brought into the greenhouse and, after air-drying and screening through a 4-mesh sieve, 15 lb. 13 oz. was placed in each of forty 2-gallon glazed pots. This provided for five phosphorus and five potassium treatments in quadruplicate. The treatment rates are shown in Tables 1 and 2. All acre-rate conversions were calculated at 2,000,000 lb.-per-acre 6 inches of air-dry soil.

The various increments of phosphorus, including no-phosphorus, were accompanied in each case by a uniform potassium treatment (starter plus soil application) assumed to be adequate (see footnote 1, Table 1). The five potassium increments were similarly accompanied by a uniform phosphorus treatment (see footnote 1, Table 2). Supplemental nitrogen was also supplied at the rate of 50 lb. of N per acre before planting, and another 50 lb. per acre in solution after the second crop of hay was harvested. Ammonium nitrate, mono-calcium phosphate and muriate of potash were used as sources of the applied nutrients. Oats and a red clover-orchard grass mixture were sown as indicator crops. Treatments 4 and 9 were

identical; therefore, the four pots of Treatment 9 were used to provide material for periodic tissue testing, while those of Treatment 4 provided yield and uptake data for the fourth rate in *both* the phosphorus and the potassium series of increments. In the potassium series, however, it is referred to throughout the paper as "Treatment 9" to avoid confusion.

The following procedure was used in applying the fertilizer and planting the seed: The top 1 inch of soil was removed from the pot and saved. The main fertilizer or "soil" treatment was thoroughly mixed with the soil in the pot to a depth of approximately 4 inches. The "starter" application of phosphorus and/or potassium was then mixed with one-half of the 1-inch layer previously removed and this starter-treated soil was spread on top in a half-inch layer. The oat, red clover and orchard grass seeds were planted on the surface and covered with the remaining half-inch layer of untreated soil. After germination the seedlings were thinned to 10 oat, 5 red clover, and 6 orchard grass plants per pot.

The oat plants were harvested 2 months after planting at the early milk stage. The red clover-orchard grass mixture grew for another 6 months. During this time, three crops of hay were harvested, as the red clover came into bloom. Yield of oven-dry tissue per pot was recorded for each crop (oats and hay). The dried plant samples were ground, ashed and analysed for phosphorus and potassium. The ashing was carried out in a muffle furnace at 500° C. for one hour, followed by wetting the ash with normal nitric acid, drying on a hotplate, and returning to the muffle for a second hour at the same temperature. The residue was taken up in dilute hydrochloric acid, the phosphorus in the solution was determined colorimetrically, using the molybdivanadate procedure of Kitson and Mellon (7) and the potassium by means of a Barclay flame photometer using lithium as the internal standard.

After the third and final cutting of hay, soil samples were taken from the pots of treatments 1, 4, 5, 6, 9, and 10. Chemically extractable phosphorus was removed from these soil samples and from the original field sample by shaking for 15 minutes with a solution of H_2SO_4 (0.05N) + NH_4Ac (0.1N) at a ratio of 1 gm. of soil to 10 ml. of extractant. The amount of phosphorus extracted was determined colorimetrically in an Evelyn colorimeter. Exchangeable potassium was extracted with neutral normal NH_4Ac according to the method of Schollenberger and Simon (11) as modified by the Department of Soils, Ontario Agricultural College (8). The potassium in the leachate was determined by means of a Barclay flame photometer using lithium as the internal standard.

RESULTS AND DISCUSSION

Crop Yield, Content and Uptake of Phosphorus

The yields of oven-dry plant tissue produced by each crop under the different phosphorus treatments are shown in Table 1. It is evident that the starter treatment of 60 lb. per acre of P_2O_5 was sufficient for maximum yield of immature oat plants. The first and second cuttings of red clover-orchard grass, however, responded to soil treatments applied in addition to the starter application. The 120 lb.-per-acre increment of P_2O_5 gave

a highly significant increase over the check treatment in the total dry matter produced by all four crops combined, but no further significant increases were obtained from heavier soil treatments. Only the two heaviest soil treatments (Treatments 4 and 5) gave a significantly higher yield of total dry matter than the starter-only treatment. Even though in some cases significant, response to applied phosphorus by oats and hay in the greenhouse, as has been observed on field plots with various crops, was comparatively small with this soil. However, during the cropping period the phosphorus-treated pots, particularly at the higher rates, contained a larger proportion of red clover to orchard grass than the no-phosphorus and starter-only pots. Phosphorus also tended to hasten blooming of the red clover.

The phosphorus content of the various crops, expressed as percentage of oven-dry tissue, is also shown in Table 1. Although each successive increment of applied phosphorus significantly increased the percentage content of phosphorus in the oat crop and the first cutting of red clover-orchard grass, this effect was not extended to the second and third cuttings except at the highest rate (480 lb. of P_2O_5 per acre). With only one or two exceptions, however, as more phosphorus was applied to the soil, more was removed by each of the four crops harvested (Table 1). Each increasing increment of phosphorus, not including the starter-only treatment, resulted in a significant increase in the total yield of phosphorus by all four crops combined.

Crop Yield, Content, and Uptake of Potassium

The influence of the various potassium treatments on crop yield and potassium content and uptake are shown in Table 2.

As with phosphorus, the starter treatment of 50 lb. of K_2O per acre placed near the seed was sufficient for maximum yield of oat plants. The starter-induced increase was significant though small. And again, as with phosphorus, the red clover and orchard grass responded, in general, only when soil treatments of potassium were applied in addition to the starter application. In no case, however, did the highest soil treatment (400 lb. of K_2O per acre) give a higher yield than the 200 lb.-per-acre rate. When the total dry matter produced by all four crops combined is considered, Treatment 8 gave a significant increase over the check treatment (Treatment 6) and the starter-only treatment (Treatment 7), but no further increases were obtained from heavier applications of potassium (Treatments 9 and 10). For the entire cropping sequence, therefore, it would appear that 60 lb. of P_2O_5 and 50 lb. of K_2O per acre placed near the seed, plus an additional 120 lb. of P_2O_5 and 100 lb. of K_2O per acre mixed with the soil, would have produced nearly maximum crop yield.

The influence of applied potassium on the percentage potassium contained in the oven-dry plant tissue and on the uptake of potassium (Table 2) also followed much the same pattern as for phosphorus. Each successive increment of applied potassium significantly increased the potassium content of the oat crop and the first cutting of red clover-orchard grass hay, but this effect was not extended to the second and third cuttings except at the highest rate (Treatment 10). When the amount of potassium

removed from the soil is considered, it will be seen that, with few exceptions, as more potassium was applied, more was removed by each of the four crops harvested (Table 2). Each additional increment of potassium, except for the starter-only treatment, resulted in a highly significant increase in the total yield of potassium by all four crops combined.

Yield-of-Phosphorus Curve

In Figure 1 the total amounts of phosphorus removed by one crop of oats plus two crops of red clover-orchard grass hay have been plotted against rates of fertilizer phosphorus applied. The close linear relationship is evident. The phosphorus removed by the third crop of hay was not included because by this stage of cropping there was little or no increase in removal with increase in addition (Table 1).

The regression equation to the line of best fit ($Y = .1186\ X + 41.7$) (Figure 1) indicates that the total yield of phosphorus at any given rate of addition was made up of 11.86 per cent of the phosphorus applied as fertilizer plus 41.7 lb. of P_2O_5 per acre from the available soil forms. A line has also been drawn from the point of origin parallel to the yield-of-phosphorus line to represent the amount of phosphorus absorbed from the fertilizer source as the rate of application was changed.

In his discussion of yield-of-phosphorus curves, Dean (4) assumed two important restrictions, namely, that the amount of nutrient absorbed from the soil is independent of the rate of fertilizer application, and that the per cent utilization of the fertilizer is the same for all rates of application. The linearity of the relationship between yield of nutrient and rate of application found in this study (Figures 1 and 2) would seem to justify the assumption of these restrictions in the present discussion also. Fried and Dean (5) have reported results showing that the per cent utilization of

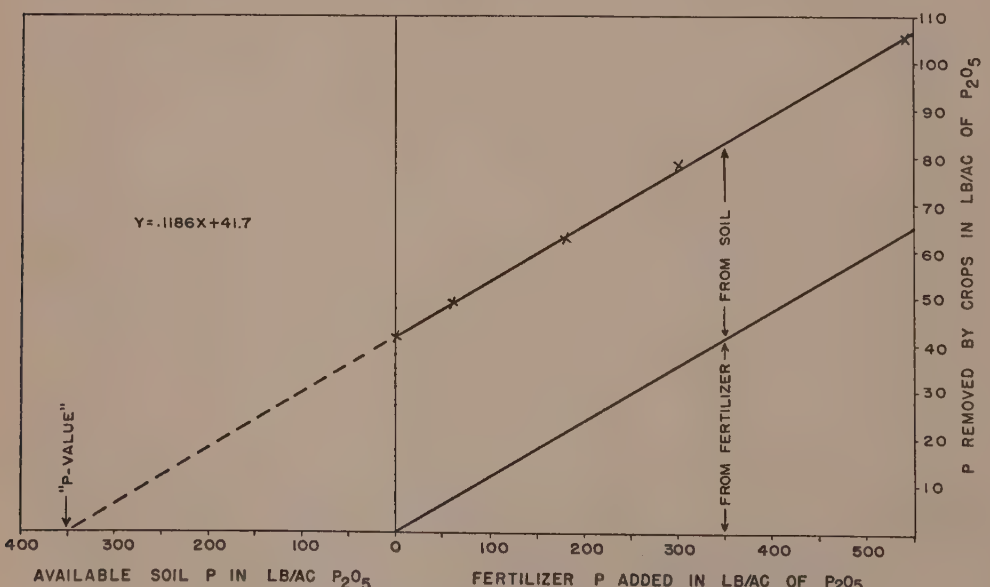

FIGURE 1. Yield-of-phosphorus curve (oats + two crops of hay).

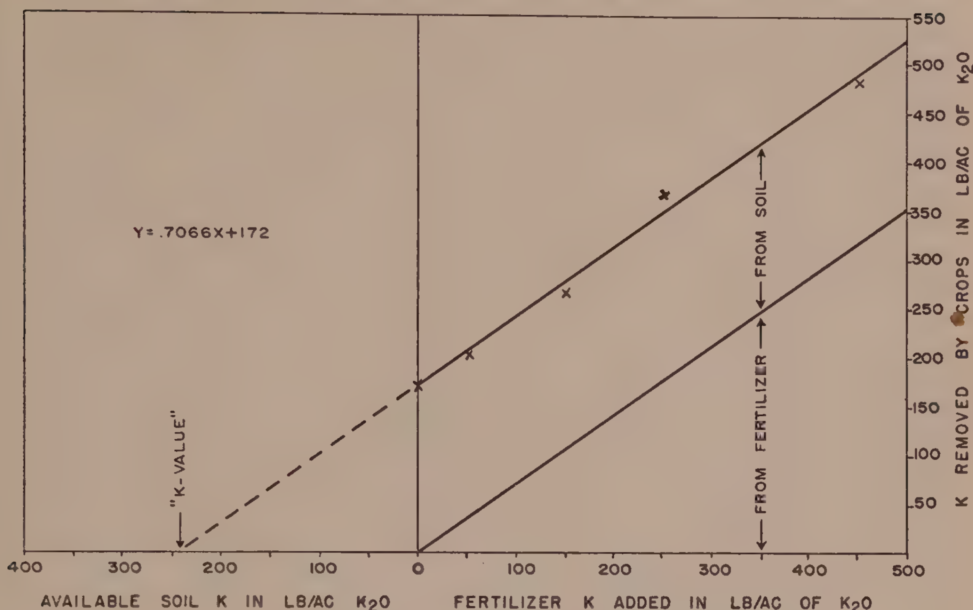

FIGURE 2. Yield-of-potassium curve (oats + three crops of hay).

phosphorus from superphosphate was independent of rate when the superphosphate was mixed throughout the soil volume. However, as Dean (4) points out, if an experiment is conducted in which fertilizer applications are extended to very high amounts, a point should be reached where yield-of-nutrient curves cease to be ascending straight lines. That is, if the rates of fertilizer application are sufficiently high, the percent utilization will not be independent of the rate of application.

Extrapolation of the yield-of-phosphorus curve to its point of intersection with the x-axis gave a "P-value" of 352 lb. of P_2O_5 per acre. The "P-value" is the amount of P_2O_5 in the soil in a form as available to the plant as the P_2O_5 of mono-calcium phosphate. Figure 1 shows that at zero addition the crops removed 41.7 lb. of P_2O_5 per acre from the native soil forms. This is 11.86 per cent of the 352 lb. per acre "P-value". If this amount (352 lb. of P_2O_5 per acre) had been added as fertilizer the plants would then have been presented with two sources of phosphorus, the soil and the fertilizer, equal in amount and availability. Under this condition equal uptake from each of the two sources would be expected as illustrated in Figure 1.

Although the soil "P-value" is high, the oat crop, as pointed out above, responded to a starter-phosphorus treatment and the first two crops of hay gave yield increases to additional soil treatments. This is understandable, however, when the percentage utilization of this soil phosphorus is considered. Only about 12 per cent of the phosphorus applied as fertilizer was utilized by the crops grown. This resulted in a large apparent content of soil phosphorus ("P-value") of which again only about 12 per cent was utilized since the soil forms measured by extrapolation of the yield-of-phosphorus curve have an availability equivalent to that of the added fertilizer. Such an estimate of the percentage of the soil phos-

phorus measured by the "P-value" (or by any soil test), and of the fertilizer phosphorus applied, which may be utilized by the crop to be grown, is of importance in predicting fertilizer requirement. Although, as Dean (4) has shown, the "P-value" is independent of the crop used to obtain it, the *percentage utilization* will vary according to the feeding powers of different plants.

Yield-of-Potassium Curve

In Figure 2 the yield-of-potassium curve has been constructed in a manner similar to the yield-of-phosphorus curve. The removal of potassium by the third crop of hay has been included since, in the case of potassium, increase in removal with increase in addition continued to the third crop of hay (Table 2). Again there was a close linear relationship between yield of nutrient and addition. Extrapolation of this linear regression gave a "K-value" of 243 lb. of K_2O per acre which is a measure of the potassium in the soil with an availability equal to muriate of potash. The regression equation to the line of best fit ($Y = .7066\ X + 172$) shows that the sequence of crops grown utilized 70.66 per cent of the potassium applied as fertilizer at each rate plus 172 lb. of K_2O per acre from the native soil forms. The latter is also 70.66 per cent of the "K-value" since the soil supply was measured as having an availability equal to the material applied as fertilizer.

Phosphorus Fixation

Table 3 shows the amounts of phosphorus extracted from the soil before and after cropping as well as the total amounts of phosphorus added as fertilizer and removed by all four crops combined. Using these data it was possible to calculate the amounts of phosphorus apparently released or fixed by the soil during the entire cropping period under zero, full rate, and double rate additions of phosphorus. These amounts also are shown in Table 3. With no fertilizer phosphorus added, the soil apparently released 38 lb. of P_2O_5 per acre during the cropping period, but when 300 lb. of P_2O_5 per acre was added to the soil before cropping, 168 lb. per acre was apparently fixed in the soil in a form not extractable by the extractant used. When 540 lb. of P_2O_5 per acre was added the apparent fixation amounted to 343 lb. per acre. These amounts represent 56 per cent and 64 per cent of the amounts applied respectively. This apparent fixation of approximately 60 per cent of the phosphorus applied as fertilizer took

TABLE 3.—APPLIED PHOSPHORUS FIXED DURING THE GROWTH OF ONE CROP OF OATS AND THREE CROPS OF RED CLOVER-ORCHARD GRASS IN THE GREENHOUSE

(All figures are in lb./ac. of P_2O_5)

Treatment number	Original soil test	Added in fertilizer	Removed by cropping	Final soil test	Amount fixed
1	83	0	72	49	−38
4	83	300	112	103	168
5	83	540	144	136	343

place during a continuous cropping period of eight months. It appears, too, to have become fixed in a form of relatively low availability to red clover and orchard grass plants since in the third crop of hay there was practically no increase in uptake of phosphorus with addition (Table 1). The capacity of this Burford loam to fix against absorption and extraction an appreciable part of the phosphorus applied as fertilizer helps to explain the lack of response of this soil to phosphorus applied to field plots, as well as the difficulty experienced in significantly raising the phosphorus soil test by annual applications of superphosphate.

Potassium Release

Table 4 shows similar values for potassium as were shown for phosphorus in Table 3.

Assuming that exchangeable potassium is the form available to plants, when no potassium was added as fertilizer 111 lb. of K_2O per acre was apparently released from the non-exchangeable to the exchangeable form. When 250 lb. of K_2O per acre was applied the apparent release amounted to only 62 lb., and when 450 lb. of K_2O per acre was applied there was apparently some fixation. This release of 111 lb. of K_2O per acre from the non-exchangeable form during the 8-month cropping period accounts for the discrepancy between the original exchangeable potassium value of 135 lb. of K_2O per acre and the extrapolated "K-value" of 243 lb. since the latter is just 108 lb. higher than the former. Apparently the "K-value" measured the exchangeable K_2O present in the soil before cropping plus the amount of potassium released from the non-exchangeable form during the period of cropping. Since the extrapolated "K-value" measures the amount of soil potassium as available to the plant as is the potassium of muriate of potash when the latter is mixed with the soil, the exchangeable potassium plus the amount released must have had an availability similar to that of muriate of potash. Of this total amount of K_2O presented to the plant (135 lb. exchangeable + 111 lb. released = 246 lb.) about 70 per cent (172 lb.) was removed by the succession of crops grown. This removal of potassium consisted of 61 lb. of K_2O per acre from the original exchangeable form (135-74 = 61) plus the 111 lb. per acre released from the non-exchangeable form. The "K-value", therefore, would seem to be of considerably more value, for some soils at least, in predicting fertilizer requirement than simply the exchangeable potassium content

TABLE 4.—NON-EXCHANGEABLE POTASSIUM RELEASED DURING THE GROWTH OF ONE CROP OF OATS AND THREE CROPS OF RED CLOVER-ORCHARD GRASS IN THE GREENHOUSE

(All figures are in lb./ac. of K_2O)

Treatment number	Original soil test	Added in fertilizer	Removed by cropping	Final soil test	Amount fixed
6	135	0	172	74	111
9	135	250	367	80	62
10	135	450	483	83	−19

itself. Again, however, it is important to have an estimation of the expected utilization of the soil and fertilizer potassium by the crop to be grown.

The continuous cropping reduced the exchangeable potassium content of the soil to approximately 80 lb. of K_2O per acre regardless of the amount of fertilizer potassium originally added (Table 4). In another experiment carried out by the author which included a soil of the Burford series from a different location, intensive cropping in the greenhouse with alfalfa reduced the exchangeable content of this soil to a similar level. Breland, Bertramson, and Borland (2) also found that cropping reduced the exchangeable potassium to a rather constant level early in the cropping sequence and thereafter the plants were dependent upon the rate at which potassium was converted from the non-exchangeable to the exchangeable form. They called this rate of conversion the potassium-supplying power of the soil. This characteristic of intensively cropped soils to retain a minimum level, typical for each soil, of unavailable exchangeable potassium against absorption has been noted by several other workers (1, 3, 10). The existence of this phenomenon casts some doubt upon the usefulness of predicting the *percentage* of the initial exchangeable potassium content of soils which may be available to the crop to be grown. The sequence of crops grown in the experiment herein reported absorbed about 45 per cent of the initial exchangeable potassium content. But, if the initial content had been higher or lower, as it might easily have been, and cropping had reduced it to the same constant level of about 80 lb. of K_2O per acre, the *percentage* of the initial content available to the plants would have, of course, been different.

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THE INFLUENCE OF POST-HARVEST RIPENING OF McINTOSH APPLES ON THE YIELD, COMPOSITION AND FLAVOUR OF THE JUICE[1]

W. D. Powrie[2] and E. A. Asselbergs[3]

Canada Department of Agriculture, Ottawa

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ABSTRACT

Juices were prepared from apples harvested at prime maturity for the fresh market and ripened after harvest at approximately 72°F. for various periods of time. A maximum juice yield, 69.0 lb. per 100 lb. of apples, was obtained on the sixth day of ripening. The acidity and ascorbic acid content of the canned juices gradually decreased with ripening while the pH values and reducing sugars increased. After reaching a maximum on the eighteenth day of ripening, the soluble solids and total sugars progressively decreased. The relative viscosity and tannin content of the canned juices were constant throughout the ripening period. Volatile reducing substances and aromatic apple flavour of the canned juices increased during apple ripening. The effect of the chemical variation of the juices on their flavour is discussed.

INTRODUCTION

Many Canadian processors hold juice apples at ambient temperatures for periods ranging from a few days to several weeks after harvest. Changes in the composition of apples during the post-harvest holding periods are reflected in the pressed juice. Neubert *et al.* (18, 19) found that, during the ripening of Delicious, Golden Delicious, Jonathan and Winesap apples at ambient temperatures, the canned juices decreased in acidity, and increased in total and reducing sugars while the tannin content remained fairly constant. The sharpness and astringency of the juices were considered more desirable when the apples were ripened for a few weeks; however, after an apple storage period of 4 to 6 weeks, some of the juices had poor flavour. During ripening, Delicious, unlike the other varieties, developed pronounced volatile aromatic components as evidenced by organoleptic analyses of the juices.

Small McIntosh apples are used extensively in Canada for the production of canned juice, yet no comprehensive data have been reported on the effect of ripening of these apples in unrefrigerated storage on the yield, composition and flavour of the juice. The type of basic information, presented in this paper, is essential before the quality of apple juice can be effectively controlled by processors.

MATERIALS AND METHODS

McIntosh apples were grown in the orchards of the Central Experimental Farm, Ottawa, and harvested on September 21, 1955, at prime maturity for the fresh market. Fruits, $2\frac{1}{4}$ to $2\frac{1}{2}$ inches in diameter with at least 70 per cent blush and no blemishes, were selected and randomized.

Orchard boxes, each containing about 40 lb. of apples, were stored for various ripening periods of time in a room maintained at a temperature of 72 ± 1°F., and with a relative humidity of approximately 60 per cent.

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[1]Contribution No. 871 from the Horticulture Division, Experimental Farms Service.
[2]Senior Food Technologist, Fruit and Vegetable Processing.
[3]Food Technologist, Fruit and Vegetable Processing.

Three boxes of apples were used for the preparation of each lot of juice. After the removal of a representative sample of apples for the pressure and starch tests, the apples were ground in a grater mill and the juice was pressed from the pulp in a rack-and-cloth press with a pressure of 3000 p.s.i. The juice was placed in 8 gallon stainless steel containers and a pectin-decomposing enzyme preparation (0.3 oz. of Pectinol A per gallon of juice) was allowed to act for twelve hours at 65 to 70°F. The clarified juice with added filter aid was filtered through nylon cloth in a plate-and-frame press filter. The filtered juice was heated to 190°F. in a stainless steel pasteurizer and conducted directly into enameled 20-ounce cans. After being sealed, the cans were inverted for approximately 20 seconds, water cooled and stored at 32 to 34°F.

For each ripening period, 15 apples were selected at random from each three-lot box for the determination of firmness and starch. The flesh firmness was measured at four pared areas on each apple, midway between stem and calyx ends, with a Magness and Taylor pressure tester using a plunger with a diameter of 7/16 of an inch. The starch content of each apple was measured according to the method reported by Phillips and Poapst (20).

The pH values of the juices were measured with a Beckman Model G pH meter. For the estimation of total acidity (as per cent malic acid), 10 ml. of juice were titrated with 0.1 N NaOH solution, using phenolophthalein as an indicator.

Reducing and total sugars (as per cent invert sugar) of the juices were determined by the Lane-Eynon method (1). Per cent soluble solids of the juices at 77°F. were measured by an Abbé refractometer. The tannin content of juices was determined by the method of Hartmann (11). Total ascorbic acid analyses were conducted according to the photometric method of the Association of Vitamin Chemists (2).

The method devised for the estimation of the total volatile reducing substances in the juices was based on the procedures reported by Friedemann and Klaas (8) and Leonard *et al.* (14). The volatile reducing substances were steam distilled from 40-ml. samples of the apple juices. The distillate of each juice sample was collected in a receiver containing 25 ml. of 0.02 N $KMnO_4$ and 10 ml. of 5.0 N NaOH. The non-condensed volatile matter was drawn by suction through a sintered glass tube into a connecting receiver containing the same volume of $KMnO_4$ and NaOH solutions as in the distillate receiver. After 175 ml. of distillate were collected, the contents of the receivers were combined in a flask, heated to 176°F., and held at this temperature for 20 minutes. To the cooled solution, 15 ml. of 10N H_2SO_4 and 1 gm. of KI were added; the volume of the solution was then brought up to 270 ml. with distilled H_2O. The liberated iodine was titrated with 0.05 N $Na_2S_2O_3$ solution using soluble starch solution as an inside indicator. For the blank determination, 40 ml. of distilled H_2O were used. The volatile reducing substances were reported as microequivalents of $KMnO_4$ per 100 ml. of juice.

Light absorption of the juices was determined in a Klett-Summerson photoelectric colorimeter, using No. 42 Blue, 54 Green, 60 Orange and 66 Red filters. The instrument was adjusted to zero with distilled H_2O.

The relative viscosity of each juice was calculated from the ratio of the time of juice flow to the time of distilled water flow. The time of flow for each liquid was determined in an Ostwald viscometer containing 5 ml. of liquid at 77°F.

Juice samples were evaluated for aromatic apple flavour by ranking and paired comparison tests (6). All samples were warmed to room temperature before they were tested by a panel of four judges. Coloured glasses were worn by each panel member to prevent detection of colour differences. At three ranking test sessions, the judges were instructed to rank five randomized samples from 1 to 5 in the order of increasing aromatic apple flavour. Juices used in the paired comparison tests were adjusted to the same sugar and acid content in order to prevent selection on the basis of sweetness or tartness.

RESULTS AND DISCUSSION

After 3, 6, 13 and 21 days of post-harvest ripening, the apples lost about 3, 6, 9 and 14 per cent, respectively, of their initial weight due to transpiration and respiration. On the thirteenth day of ripening, slight wrinkling of the apple skins was observed.

Firmness and starch content of apple flesh were used in this study to aid in the evaluation of ripeness of the apples. During the first 13 days of ripening, the pressure-test values decreased progressively as shown in Table 1. However, the pressure-test reading of 14.6 lb. on the eighteenth day of ripening indicated that the apple flesh was firmer or tougher than the flesh of apples ripened for 13 days. This increase in flesh firmness or toughness may be attributed to the extensive moisture loss of the flesh. The influence of the moisture content of fruit on the pressure-test values has been reported (10). Morris (16) found an increase in the pressure-test readings of stored apples and suggested that wilting was responsible for the increase. Neubert *et al.* (19) observed that with the post-harvest ripening of small Winesap and Jonathan apples in unrefrigerated storage, the pressure-test values decreased progressively. However, it should be noted that only three values were reported for each variety throughout a one-month storage period. In the present study, small amounts of starch [Stage 7 on the Horticulture Division chart (20)] were found in the apple flesh at the beginning of the storage period but after three days of ripening starch was not detectable in the apples by the method used. Apparently the more objective of the two methods used for evaluating post-harvest ripening of the apples was the pressure-test.

Data in Table 1 indicate that after 6 days of apple ripening, a maximum yield of juice was obtained. The softening of the flesh, as evidenced by the pressure-test values, was probably responsible for the high yield. The softening of apples after harvest has been associated with the hydrolysis of insoluble protopectin to soluble pectin (9). The decrease in juice yield, during the ripening of the apples beyond 6 days, presumably could be due to a loss of moisture from the stored apples.

Results of chemical analyses of the canned apple juices, which were obtained from apples ripened for various periods of time, are presented in Table 1. The pH and total acidity values of the juice steadily increased

TABLE 1.—EFFECT OF RIPENING OF MCINTOSH APPLES ON THE YIELD AND CHEMICAL COMPOSITION OF THE JUICE

Apples		Juice	Canned Juice							
Days of ripening	Average[1] pressure	Yield	pH	Total acidity	Soluble solids	Reducing sugars	Total sugars	Tannin	Total ascorbic acid	Soluble solids / acid ratio
	lb.	lb./100 lb. apples		% malic acid	%	% invert sugar	% invert sugar	%	mgm./100 ml.	
0	18.3	68.3	3.52	0.535	13.2	8.95	11.23	0.034	1.6	24.7
3	17.4	67.4	3.58	0.489	13.2	9.40	11.61	0.040	1.4	27.0
6	15.6	69.0	3.64	0.452	13.2	8.95	11.45	0.040	1.4	29.2
10	14.8	66.6	3.70	0.417	13.5	9.10	11.87	0.041	1.2	32.4
13	13.5	64.7	3.75	0.390	13.7	9.25	11.89	0.041	1.2	35.0
18	14.6	63.2	3.83	0.347	14.0	9.80	12.01	0.041	1.2	40.4
21	13.4	62.8	3.86	0.328	13.7	10.00	11.71	0.041	1.0	41.7
25	13.6	63.0	3.93	0.297	13.5	10.00	11.58	0.042	0.9	45.5
32	—	62.4	4.08	0.258	13.3	10.15	11.45	0.043	0.8	51.6

[1]Average of 60 pressure-test readings.

and decreased, respectively, during ripening of the apples. With 3 days of ripening, both the total and reducing sugars increased. Since the starch disappeared during this ripening period, it may be assumed that the starch in the apple flesh was rapidly converted into various types of sugars. Both the reducing and total sugars of the juices decreased between the third and the sixth days of ripening; thereafter the reducing sugars continually increased with further ripening while the total sugars increased up to the eighteenth day and then decreased. No appreciable change in tannin values of juice was apparent. Fellers, Cleveland and Clague (7) found that the ascorbic acid content of Baldwin apples tended to decrease during storage at 36°F. In the present study, the amount of total ascorbic acid in the juice was found to be definitely related to the ripening time of the apples.

Charley (4) and Neubert (17) have indicated that the body of apple juice contributes to the quality of the juice. Since Clague and Fellers (5) reported that cider became more viscous with apple storage time, it was reasoned that those viscosity-contributing components, which are not removed by clarification and filtration, may increase in the canned juices with apple ripening. Table 2 indicates that the relative viscosity of the juices did not change appreciably with the ripening period of the apples. Similar relative viscosity values of clarified juices obtained from ripe and over-ripe apples were reported by Joslyn *et al.* (12).

The colour of apple juice is an important factor in the quality evaluation of the product. In this study the juice was initially light amber-brown in colour, and, with increased apple ripening up to the thirteenth day, the colour of the juices became darker. With 10, 18, 21 and 25 days of ripening, the juices were judged visually as similar in colour. Juices, with the deepest brown colour, were prepared on the thirteenth and thirty-second days of ripening. In order to evaluate objectively the colour changes in the juices, light absorption of the juices was measured in several regions of the visible spectrum. Table 2 indicates that the most significant changes in light absorption of the juices were exhibited with No. 42 Blue

TABLE 2.—EFFECT OF RIPENING OF MCINTOSH APPLES ON THE CHEMICAL AND PHYSICAL PROPERTIES OF THE CANNED JUICE

Days of ripening	Relative viscosity	Light absorption—Colorimeter reading, Filter Number: 42 Blue	54 Green	60 Orange	66 Red	Volatile reducing substances[1]
0	1.35	199	49	17	16	675
3	1.37	200	55	22	18	681
6	1.37	261	69	25	19	694
10	1.37	262	68	21	17	750
13	1.37	307	82	24	19	775
18	1.37	247	66	22	13	910
21	1.38	230	66	22	16	910
25	1.37	279	71	23	20	925
32	1.37	289	79	23	26	1075

[1]Microequivalents of potassium permanganate per 100 ml. of apple juice.

TABLE 3.—EFFECT OF RIPENING OF MCINTOSH APPLES ON THE AROMATIC APPLE FLAVOUR OF THE CANNED JUICE

Days of ripening	Volatile reducing substances[1]	Ranking[2]	
		Mean	Standard deviation
0	675	1	0
10	750	2.11	0.28
13	775	2.89	0.28
18	910	4.00	0
25	925	5.00	0

[1]Microequivalents of potassium permanganate per 100 ml. of apple juice.
[2]A taste panel of four judges ranked the juices from 1 to 5 in the order of increasing aromatic apple flavour at three sessions.

and 54 Green filters. With these filters, the transmission readings increased with ripening periods up to the thirteenth apple ripening day. No explanation can be given for the decrease of the transmission readings after this period.

Since some objective method for evaluating the aromatic flavour of apple juice would be advantageous, the amount of volatile reducing substances in the juices was determined. As the apples ripened, the content of volatile reducing substances progressively increased in the canned juice (Table 2). Between the sixth and eighteenth days and the twenty-fifth and thirty-second days of apple ripening the amount of volatile reducing substances of the juices increased at a rapid rate. White (21) reported that the volatile matter in an apple juice concentrate consisted of 92 per cent alcohols, 6 per cent carbonyl compounds and 2 per cent esters. Probably the principal volatile reducing components in the canned apple juice of this study were the alcohols. Table 3 indicates that the aromatic apple flavour and the amount of volatile reducing substances of the juices increased with apple ripening. Moreover, the results from the paired comparison tests also indicated this relationship. Although juices prepared from apples ripened for 32 days had a high degree of aromatic apple flavour, an undesirable storage flavour could be detected. Luh *et al.* (15) found that the volatile reducing substances and flavour score of canned pears increased with the ripening of the fresh fruit; with over-ripe pears off-flavours were detected in the canned product. The data of the present study suggest that the content of volatile reducing substances in apple juice may be valuable in objectively evaluating the aromatic apple flavour and may also be an index of off-flavour. Moreover, since the pressure-test cannot be used for the estimation of apple ripeness after a few weeks of unrefrigerated storage, the amount of total volatile reducing substances in the apple flesh might be a useful criterion of ripeness.

The variation of the chemical composition of the juices resulted in significant flavour changes. The taste panel observed that the juices, increasing in soluble solids-acid ratio (Table 1), progressively increased in sweetness and decreased in astringency. Since the tannin content of the juices remained constant, the degree of astringency was dependent on the amount and proportion of the acid and sugar in the juices. Cald-

well (3) pointed out that the taste of apple juice depends on the relative proportions of acids, sugar and astringent materials, and that small differences in the proportion of these components in juice can be readily perceived. As yet, no studies have been reported on the changes of specific volatile components in juice with apple ripening and on the effect of these changes on the juice flavour. However, the data presented herein indicate that there is a definite relationship between the content of volatile reducing substances and the aromatic apple flavour of the juices under the conditions of the experiment.

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INHERITANCE OF REACTION TO LOOSE SMUT, *USTILAGO NUDA*, AND TO STEM RUST, *PUCCINIA GRAMINIS TRITICI*, IN BARLEY[1]

J. E. ANDREWS

Canada Department of Agriculture, Lethbridge, Alberta

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ABSTRACT

Inheritance of reaction to two races of *Ustilago nuda* (Jens.) Rostr. was studied in crosses between the barley varieties Anoidium, Valentine, and Montcalm. Valentine is resistant to one race, designated as Vr, and susceptible to the other, designated as Vs. Anoidium is resistant and Montcalm susceptible to both races.

Data from F_1, F_2, F_3, and backcross progenies indicated that the resistance of Valentine to race Vr was controlled by a single dominant gene and the resistance of Anoidium by a single recessive gene. The two genes were found to be independent. The recessive gene was designated as un7.

Data from two crosses and one backcross indicated that the resistance of Anoidium to race Vs was due to a single dominant gene. Deviations from this hypothesis in a third cross are explainable on the basis of greater mortality of resistant than of susceptible genotypes.

In crosses with the resistant variety Valentine, mature plant reaction to race 56 and seedling reaction to race 15B of *Puccinia graminis tritici* Eriks. and Henn., were controlled by a single gene with resistance being dominant. Greenhouse temperatures between 80 and 85°F. were satisfactory and those between 65 and 70°F. were unsatisfactory for differentiating between resistance and susceptibility to stem rust.

Genes for resistance to stem rust and to race Vr of *U. nuda* in the variety Valentine were found to be linked. The recombination value obtained from backcross and F_3 data was 9.2 ± 1.8 per cent.

INTRODUCTION

Loose smut of barley caused by *Ustilago nuda* (Jens.) Rostr., may be controlled by seed treatments but such methods generally are applicable only to small seed lots. The development of varieties resistant to the disease offers a more practical method of control.

Physiological specialization in *U. nuda* (1, 14), complicates the development of resistant varieties. Varieties such as Trebi and its derivatives, which were formerly used as sources of resistance, are susceptible to races now widespread and breeders have turned to new sources of resistance.

A number of investigations of the inheritance of reaction to loose smut in barley have been reported. Smith (13) reviewed early studies. Livingston (4) reported a single dominant gene for resistance in both Trebi and a selection of *Hordeum deficiens*, and a weak gene for resistance in Missouri Early Beardless. These genes have been assigned the symbols Un and Un2 respectively by Robertson *et al.* (7). Schaller (9) confirmed Livingston's findings concerning Trebi and demonstrated the presence of single genes Un3, Un4, and Un5 for resistance in the varieties Jet, Dorsett, and selections X173-10-5-6-1 respectively. He concluded that the Trebi gene was independent of the Jet and Dorsett genes but there was an indication

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of linkage between the latter two. Using a composite inoculum which did not infect the variety Trebi, Mohajir *et al.* (5) found the resistance of Abyssinian and of Jet to be dominant and conditioned by two factor pairs. This indicates a gene for resistance in the Jet variety in addition to the one reported by Schaller (9).

Since the present investigation was started, two inheritance studies using more than one physiologic race of *U. nuda* have been reported. Skoropad and Johnson (12) found the resistance of Titan and of Jet to a race designated as Tr to be governed by single dominant genes, which they presumed to be Un and Un3 respectively. They also reported the resistance of Jet to race Ts to be governed by a single dominant gene which they provisionally designated as Un6. Konzak (3) showed that the varieties Jet and Valki each possessed a single dominant gene for resistance to race 1, two independent genes for resistance to races 4 and 8, and two for resistance to races 3 and 7. Both Valki genes or either of the Jet genes were required for resistance to races 3 and 7. Resistance to race 6 was governed by a single factor in Jet and two factors in Valki.

Genes for loose smut and stem rust resistance in a selection from the cross Chevron × Trebi were reported to be linked (11). Inheritance studies indicated that the resistance of Chevron to stem rust is controlled by a single dominant gene (13).

A knowledge of linkage between important characters and of their mode of inheritance is valuable to the plant breeder. The objectives of the present investigation were to study, in certain barley crosses, the inheritance of reaction to two races of *U. nuda*, one virulent and one avirulent on Trebi, the inheritance of reaction to races 56 and 15B of *Puccinia graminis tritici* Eriks. and Henn., and linkages between genes for resistance to the two diseases.

MATERIALS AND METHODS

Loose Smut Studies

Two collections of *U. nuda* differing in virulence were used in this study. These are designated as races Vr and Vs. Race Vr is not virulent on Trebi or Valentine and was increased on the variety Montcalm. Race Vs causes high infection in Trebi and Valentine and was increased on Valentine to screen out less virulent mixtures. To facilitate identification of these races, a series of tester varieties was inoculated with them. Reactions of tester varieties were based on the average infection in two replicates from bulked seed of 10 inoculated heads.

The parents of the hybrid populations studied were the varieties Anoidium (C.A.N. 177), Valentine (C.A.N. 198), and Montcalm (C.A.N. 1135). Anoidium is resistant to both races of *U. nuda* used in the study. Valentine, a selection from the cross Chevron × Trebi, is resistant to *U. nuda* race Vr but susceptible to race Vs; it is also resistant to the common races of *P. graminis tritici*. Montcalm, a malting barley widely grown in Canada, is susceptible to both organisms.

The modified partial vacuum method of inoculation (2) was used in most of this investigation. An aqueous suspension of about 0.5 per cent by volume of freshly collected chlamydospores of *U. nuda* was used as

inoculum. Plants from this inoculated seed were grown in the field. The "hypodermic" method (6) was used to inoculate some crosses which were studied further in the following year. In this case, a 3 per cent suspension of *U. nuda* was used as inoculum and the seeds were planted in the greenhouse.

In accordance with the findings of other workers (4, 8, 9, 10), each head was inoculated when dehiscence of the anthers had occurred in about two-thirds of its florets. Spikelets from the two upper and two lower rachis nodes were removed because they are generally late in flowering. All inoculated seed was treated with an organic mercury dust to reduce infection by other microorganisms.

Hybrid material was tested in the F_1, F_2, F_3, and backcross generations. The reaction of the F_1 generation was obtained by inoculating flowers of the female parent 24 hours after cross pollination and growing the plants from the crossed seed produced. The F_2 reaction was obtained by growing seed from inoculated F_1 plants. Tests on F_3 lines were made by inoculating F_2 plants selected at random from smut-free F_2 populations. Where possible, four heads on each F_2 plant were inoculated, two with race Vr and two with race Vs. In addition, seed from at least one non-inoculated head was saved for rust reactions. Inoculated heads were seeded as individual head rows in the field. Head rows of inoculated seed of the parents were grown as checks. Similarly, F_1 plants from backcrosses were inoculated with both races of smut and reserve seed was saved for a rust test. The plants were pulled after heading and their loose smut reaction was recorded as either resistant or susceptible. Reactions of F_3 lines were based on an average of 27 plants per line. Lines with less than 10 plants were not used in the genetic interpretations.

Stem Rust Studies

Stem rust reactions of the F_1, F_2, and F_3 of crosses between the resistant variety Valentine and the susceptible varieties Moncalm and Anoidium, and backcrosses to the respective susceptible parents were studied both in the field and in the greenhouse. Race 56 of *P. graminis tritici* was used in the field studies and race 15B* in the greenhouse studies.

Because Lethbridge, Alberta, is in a semi-arid area, the usual method of establishing an artificial epiphytotic of stem rust in the field was modified. Border rows of a susceptible variety, Little Club, were dusted with urediospores of race 56 of *P. graminis tritici* and covered overnight with a low plastic tent to raise the humidity. When uredial pustules began to appear on these plants, the nursery was flood-irrigated.

The nursery consisted of F_1 and F_2 plants, F_3 lines, and backcross progeny rows. Parental varieties were included as checks at intervals of 20 rows. Mature plants were pulled and classified as resistant or susceptible by using the reactions of the resistant and susceptible parents as standards.

The reactions of randomly selected F_3 lines and of progenies of backcross plants to race 15B were studied in the seedling stage in the greenhouse at the University Farm, St. Paul, Minnesota. Approximately 20

*Designated as collection 51-39-57 by the Federal Rust Laboratory, St. Paul, Minn.

seeds of each line were sown in individual 4-inch pots. The parental varieties were included as checks at regular 20-pot intervals. Seedlings were inoculated with stem rust at the one-leaf stage. This study was repeated at greenhouse temperatures of between 65 and 75°F. and between 80 and 85°F. The only exception was at the time of inoculation when the seedlings were kept in a humidity chamber for 36 hours at about 60°F. About 14 days after inoculation, the plants were pulled and classified as resistant or susceptible.

EXPERIMENTAL RESULTS

Loose Smut Studies

Reaction of Tester and Parental Varieties

The reactions of the tester varieties to races Vr and Vs of *U. nuda* are shown in Table 1. These data indicate that the two are distinct pathogenic races.

TABLE 1.—REACTION OF TESTER AND PARENTAL VARIETIES TO RACES VR AND VS OF *U. nuda*

Variety	C.A.N.	Per cent infection	
		Race Vr	Race Vs
Testers			
Wh. Hulless	785	83.3	0.0
O.A.C. 21	1086	79.8	13.5
Regal	742	59.6	62.7
Bay	112	9.5	17.5
Warrior	1144	0.0	85.0
Trebi	1115	0.0	50.0
Titan	1164	1.9	9.4
Compana	1154	0.0	100.0
Valki	139	0.0	93.7
Parents			
Montcalm	1135	61.7	60.8
Valentine	198	2.7	60.9
Anoidium	177	3.9	0.0

TABLE 2.—LOOSE SMUT REACTION OF F_1 AND F_2 GENERATIONS OF VARIOUS BARLEY CROSSES AND THEIR RECIPROCALS WHEN INOCULATED WITH RACES VR AND VS OF *U. nuda*

Hybrid	Generation	Race Vr		Race Vs	
		Total plants	Infection	Total plants	Infection
		No.	per cent	No.	per cent
Valentine × Montcalm	F_1	29	0.0		
Montcalm × Valentine	F_1	42	0.0		
Montcalm × Valentine	F_2	214	12.2	265	62.6
Valentine × Anoidium	F_1	25	0.0	34	0.0
Anoidium × Valentine	F_1	38	0.0	25	0.0
Anoidium × Valentine	F_2	108	1.9	76	28.9
Anoidium × Montcalm	F_2	139	57.6	108	24.7

TABLE 3.—DISTRIBUTION IN INFECTION CLASSES OF PARENT ROWS AND F_3 AND BACKCROSS PROGENIES WHEN INOCULATED WITH *U. nuda*, RACE VR

Parent or cross	Number of rows or progenies in 5 per cent infection classes																			Total
	0	0.1 – 4.9	5 – 9.9	10 – 14.9	15 – 19.9	20 – 24.9	25 – 29.9	30 – 34.9	35 – 39.9	40 – 44.9	45 – 49.9	50 – 54.9	55 – 59.9	60 – 64.9	65 – 69.9	70 – 74.9	75 – 79.9	80 – 84.9	85 – 100	
Montcalm								1	1	2	5	4	1	5	2	3		3	3	30
Valentine	13	2	2			1														18
Anoidium	10		1	3	2															16
Montcalm × Valentine	61	27	21	22	8	13	4		2	8	5	4	12	3	4	4	2	6	4	210
Montcalm × F_1 (Montcalm × Valentine)	8	10	8	5	1	3		5	8	7	9	3	5	1	3	3	1	2		82
Anoidium × Valentine	55	8	7	6	2	3	4	2	1	3	1	3	2		3	2				102
Montcalm × Anoidium	14	1	2	6	3	9	4	5	8	8	1	13	3	5	2	3	3	3	4	97
Montcalm × F_1 (Anoidium × Montcalm)		1	3	2	2	3	5	4	4	4	5	7	4	4	5	7	1	2		63
Anoidium × Montcalm (green-house study)	16	2	3	10	3	5	8	1	5	7	3	4	1	1	1	2	1	4	3	80

TABLE 4.—DISTRIBUTION IN INFECTION CLASSES OF PARENT ROWS AND F_3 AND BACKCROSS PROGENIES WHEN INOCULATED WITH *U. nuda*, RACE VR

Parent or cross	Number of rows of progenies in 5 per cent infection classes																			Total
	0	0.1 – 4.9	5 – 9.9	10 – 14.9	15 – 19.9	20 – 24.9	25 – 29.9	30 – 34.9	35 – 39.9	40 – 44.9	45 – 49.9	50 – 54.9	55 – 59.9	60 – 64.9	65 – 69.9	70 – 74.9	75 – 79.9	80 – 84.9	85 – 100	
Montcalm								1	1	2	5	4	1	5	2	3		3	3	30
Valentine					1	1	1	1		2		4	1	2	3		1	1	4	22
Anoidium	17																			17
Anoidium × Valentine	37	7	17	21	5	7	2	5	4	3	4	5	3	2	1		1	1	3	128
F_1 (Anoidium × Valentine) × Valentine	4	3	8	6	6	2	5	5	3	4	1	2	1	1	1	1	1	1		55
Anoidium × Montcalm (green-house study)	19		12	15	12	5	7	2	3	4		5	1	2	1	2	3	2		95
Montcalm × Anoidium	17	1	7	6	7	7	8	6	5	9	4	6	5	6	8	5	5		9	121
Montcalm × F_1 (Anoidium × Montcalm	2	1	4	2	7	6	2	8	2	5	3	3	7	3	4	1	2	1	1	64

The reactions of the parental varieties (Table 1) show that Montcalm is susceptible to both races Vr and Vs, Valentine is resistant to Vr but susceptible to Vs, and Anoidium is resistant to both.

Inheritance of Reaction to Race Vr in Crosses with Valentine

In the F_1 of reciprocal crosses between Montcalm and Valentine there was no infection and in the F_2 of Montcalm × Valentine there was 12.2 per cent infection (Table 2). This indicates resistance of Valentine to Vr is inherited as a dominant character.

Among the F_3 lines of Montcalm × Valentine (Table 3) there is a complete break in the distribution at the 30 to 34.9 per cent class. Because no line of the susceptible parent Montcalm had less than 30 per cent infection (Table 3), and because the F_1 and F_2 indicated that resistance is dominant, this seemed a logical point of separation of the susceptible from the resistant and segregating lines. On this basis there were 156 resistant and segregating, and 54 susceptible lines. This ratio was in satisfactory agreement ($X^2 = 0.06$, $P = 0.90 - 0.80$) with the expected on the basis of a 3 : 1 ratio.

Among the backcross lines of Montcalm × (Montcalm × Valentine), segregating and susceptible lines in a ratio of 1 : 1 would be expected if a single dominant gene were involved. Using the 30 per cent level of infection to separate these two phenotypes as in the F_3, there were 35 segregating and 47 susceptible lines. This ratio was in satisfactory agreement with the expected ($X^2 = 0.87$, $P = 0.50 - 0.30$). Thus the F_1, F_2, F_3, and backcross data indicated that the resistance of Valentine to race Vr is governed by a single dominant gene.

Inheritance of Reaction to Race Vr in Crosses with Anoidium

Seed and seedling mortality was greater in the F_3 of Montcalm × Anoidium grown in the field than in other crosses. There was an average of 17 plants per F_3 line in this cross as compared to 27 for all crosses. If loose smut reaction is associated with this mortality, and particularly if the low infection in Anoidium is a result of mortality of infected seeds or seedlings rather than inherent resistance, then this must be considered in the genetic interpretation of the data. Consequently, before attempting genetic interpretation of data from the above crosses, further studies were made. Eighty F_2 plants from the reciprocal cross, Anoidium × Montcalm, were inoculated with race Vr by the "hypodermic" method and their progeny grown in the greenhouse. The average per cent survival and per cent infection of the parents and of the F_3 lines classed phenotypically were:

Variety or phenotype	Stand	Infection
	per cent	per cent
Anoidium	56.5	0
Montcalm	62.5	53.2
Resistant F_3 lines	60.2	0
Segregating or susceptible F_3 lines	57.9	5–80

If the resistance of Anoidium resulted from the failure of all infected seeds to germinate, then stands for this variety and for F_3 lines with no observed infection should be reduced to a much greater extent than those of the susceptible variety Montcalm and lines classified as susceptible. This was not the case. Furthermore, there was no significant correlation between stand and infection and mortality was similar to that observed by other workers. It was assumed, therefore, that mortality occurred at random among the segregating genotypes and need not be considered further in the genetic interpretation of these data.

There was 57.6 per cent infection in the F_2 of Anoidium × Montcalm (Table 2). This suggests that resistance is either recessive or controlled by the interaction of several factors. Assuming a single recessive gene, the 15 per cent level of infection was selected as the most logical point of separation of resistant from segregating and susceptible lines in the F_3 of Montcalm × Anoidium (Table 3). Because about 10 per cent of the backcross lines had less than 15 per cent infection, a few segregating F_3 lines might be included in the group classified as resistant; similarly, a few resistant lines might have more than 15 per cent infection, as did two rows of the resistant parent, Anoidium. However, misclassification in either direction should be about equal and the true ratio disturbed only slightly. On this basis, 23 F_3 lines were classified as resistant and 74 as segregating or susceptible. This was close to the expected on the basis of a 1 : 3 ratio ($X^2 = 0.08$, $P = 0.80 - 0.70$).

The distribution of F_3 lines of Anoidium × Montcalm grown in the greenhouse was similar to that of the reciprocal cross grown in the field. In the greenhouse, Anoidium showed no infection; therefore, it is assumed that the F_3 progeny rows from homozygous resistant F_2 plants would also show no infection. Because all of the heterozygous backcross lines (Table 3) showed some infection, the zero class should include no heterozygous F_3 lines. Considering the 16 F_3 progenies with zero infection as homozygous resistant and the remaining 64 as segregating or susceptible, the distribution fitted a 1 : 3 ratio with a probability of 0.50 to 0.30.

No attempt was made to separate segregating from susceptible F_3 lines because a considerable overlapping of the two classes was expected. Similarly, no attempt was made to separate genotypes in F_2 progenies of the backcross Montcalm × (Anoidium × Montcalm) where lines that segregated 1 resistant : 3 susceptible and lines that were homozygous susceptible were expected in a ratio of 1 : 1. However, the high proportion of these backcross progenies with over 25 per cent infection (Table 3) was as expected with a recessive gene for resistance.

In the resistant × resistant cross, Anoidium × Valentine, a number of F_3 lines with a high percentage of infection were obtained (Table 3) indicating that the genes for resistance in the two varieties are different. Data from other crosses indicate that the resistance of Valentine is controlled by a single dominant gene and that of Anoidium by a single recessive gene. Assuming independent segregation of these two genes in the cross Anoidium × Valentine, the following classes of F_3 lines are expected:

Class	Frequency
Homozygous resistant	7
Segregating 13R : 3S	4
Segregating 3R : 1S	2
Segregating 1R : 3S	2
Homozygous susceptible	1

Considering theoretical distributions of the expected genotypes and the observed distributions of the F_3 lines of Montcalm × Valentine and backcross lines of Montcalm × (Anoidium × Montcalm) (Table 3), the 25 per cent level of infection should separate, with a minimum of misclassification, the first three from the latter two of the classes listed above. It was not possible to distinguish between the other phenotypic classes because of the overlapping of infection classes. The 25 per cent level of infection divided the F_3 lines of Anoidium × Valentine (Table 3) into two groups in a ratio of 81 : 21 which corresponded satisfactorily ($X^2 = 0.21$, $P = 0.70 - 0.50$) to the expected 13 : 3 ratio. Thus, data from all crosses with Anoidium indicated that its resistance is controlled by a single recessive gene, which is independent of the dominant gene for resistance in Valentine.

Inheritance of Reaction to Race Vs

Montcalm and Valentine are susceptible and Anoidium is resistant to race Vs of *U. nuda* (Table 1). The percentages of smutted plants observed in the inoculated F_1 and F_2 of crosses between these varieties are given in Table 2, and the distributions in 5 per cent infection classes for F_3 backcross lines in Table 4.

In reciprocal crosses between Anoidium and Valentine no infection occurred in the F_1 generation (Table 2) indicating that resistance was dominant. The observed distribution of F_3 lines of Anoidium × Valentine (Table 4) suggested a single dominant factor for resistance, although the 28.9 per cent infection obtained in the F_2 (Table 2) was higher than expected on this basis. Anoidium was completely resistant to this race and there was a low point in the F_3 distribution at the 25 per cent level. Therefore, it was assumed that the zero and 25 per cent levels of infection would separate the resistant, segregating, and susceptible F_3 lines (Table 4) with a minimum of misclassification. On this basis, the observed ratio of 37 resistant : 57 segregating : 34 susceptible was in satisfactory agreement ($X^2 = 1.67$, $P = 0.50 - 0.30$) with the calculated 1 : 2 : 1 ratio. Although the data from the backcross (Anoidium × Valentine) × Valentine (Table 4) showed that some heterozygous F_3 lines might fall in the zero class, the number erroneously classified should be too small to disprove the hypothesis.

Assuming a single dominant gene for resistance, lines segregating 3R : 1S and homozygous susceptible lines are expected in a ratio of 1 : 1 among the backcross progenies of (Anoidium × Valentine) × Valentine (Table 4). Using the 25 per cent level of infection as a point of separation, 29 lines were classified as segregating and 26 as susceptible. This agreed satisfactorily ($X^2 = 0.16$, $P = 0.70 - 0.50$) with the expected 1 : 1 ratio.

As was the case when inoculated with race Vr, seed and seedling mortality was high in the F_3 progeny of Montcalm × Anoidium inoculated with race Vs and grown in the field. Additional F_2 plants of the reciprocal cross, Anoidium × Montcalm, were inoculated and the seed was planted in the greenhouse.

The distribution in 5 per cent infection classes of 95 F_3 lines of Anoidium × Montcalm studied in the greenhouse is given in Table 4. There was a complete break in the distribution between the zero and the 5 per cent classes; all lines of the resistant parent showed no infection and all those of the susceptible parent at least 30 per cent infection; the F_2 (Table 2) had 24.7 per cent infection. Therefore, the zero and 30 per cent levels of infection were selected as the most logical points of separating resistant, segregating, and susceptible lines. Thus divided, the distribution fitted a 1 : 2 : 1 ratio with a probability of 0.70 to 0.50.

The per cent survival and range of infection of the parents and the three classes of F_3 lines of Anoidium × Moncalm inoculated with Vs and grown in the greenhouse were:

Variety or F_3 class	Survival	Range of Infection
	per cent	per cent
Anoidium	50.0	0
Montcalm	67.5	30–80
Homozygous resistant	48.6	0
Segregating	57.2	5–29
Homozygous susceptible	61.4	30–85

Survival was lowest in the resistant parent Anoidium and in the F_3 lines that were classified as resistant. The percentage data for stand and infection in F_3 lines were transformed to angles (angle = arc sin $\sqrt{\text{percentage}}$) and the correlation between stand and infection was calculated. The coefficient of correlation of +0.251 was significant at the 5 per cent level. However, using r^2 interpretation, only 6.3 per cent of the variation in percentage of smut was associated with variation in stand. Thus, reduced stand appeared to be associated with the resistant genotypes, but the reduction was not sufficient to account for differences in smut reaction. Therefore, it was assumed that the low infection in Anoidium and certain F_3 lines was influenced only slightly by the failure of infected seeds to survive.

The distribution of F_3 lines of Montcalm × Anoidium inoculated with race Vs and grown in the field (Table 4) were not as expected ($P = 0.05 - 0.01$) on the basis of the single dominant gene for resistance indicated in other crosses with Anoidium. The number of lines with no infection, which might be considered as homozygous resistant, was fewer than expected and the distribution was skewed toward the susceptible side. The distribution of backcross progenies of Montcalm × (Anoidium × Montcalm) (Table 4) was similarly skewed toward the susceptible side more than expected on the basis of a single dominant gene for resistance.

This may have been the result of selective mortality of certain genotypes. Greenhouse data indicated a small but significant correlation between low infection and reduced stands. In the field, where mortality was greater- an association between mortality and resistance would result in a distri, bution skewed toward the susceptible side.

Association of Reaction

The reactions of 78 F_3 lines of Anoidium × Montcalm to races Vr and Vs of *U. nuda* were obtained in the greenhouse. A X^2 for independence test for reaction to the two races gave a P value greater than 0.01 indicating association of reaction.

Reactions to both races were obtained for only 58 F_3 lines of Montcalm × Anoidium grown in the field. A X^2 test for independence gave a P value of 0.50 to 0.30 indicating no association of reaction to the two races. Similarly, a X^2 test indicated no association of reaction to the two races for 51 backcross lines of Montcalm × (Anoidium × Montcalm). Because the number of lines available for studies of association of reaction in each cross was relatively small, and because there was lack of agreement between results from field and greenhouse, no conclusions were drawn as to association or independence of reaction to races Vr and Vs of *U. nuda*.

Stem Rust Studies

Inheritance of Reaction to Stem Rust in the Field

Race 56 of *P. graminis tritici* was used as inoculum in the field and, since little natural infection occurred in the area in which the material was grown, it was assumed that reactions observed were due to this race. The reactions of the parents used to classify plants as resistant or susceptible at maturity are shown in Figure 1.

In the cross Montcalm × Valentine, the F_1 was resistant and the observed distribution of the 213 F_3 progeny rows (Table 6)was similar

TABLE 5.—REACTION OF THE F_2 PROGENY OF MONTCALM × VALENTINE AND ANOIDIUM × VALENTINE TO STEM RUST IN THE FIELD

Cross	No. of plants		Fit to a 3 : 1 ratio	
	Resistant	Susceptible	X^2	P
Montcalm × Valentine	169	39	4.33	.02–.05
Anoidium × Valentine	139	59	2.43	.10–.20

TABLE 6.—REACTION OF THE F_3 PROGENY ROWS OF MONTCALM × VALENTINE AND ANOIDIUM × VALENTINE TO STEM RUST IN THE FIELD

Cross	No. of lines			Fit to a 1 : 2 : 1 ratio	
	Res.	Seg.	Susc.	X^2	P
Montcalm × Valentine	59	100	54	1.03	.50–.70
Anoidium × Valentine	21	39	18	0.24	.80–.90

to that expected on the basis of a single dominant gene for resistance. The number of F_2 plants classified as susceptible was lower than expected on the basis of a 3 : 1 ratio (Table 5) but this may have been the result of some susceptible genotypes escaping infection. In the backcross Montcalm $\times$ F_1 (Montcalm $\times$ Valentine), there were 37 segregating and 53 susceptible lines. These are in satisfactory agreement ($X^2 = 2.84$, $P = 0.10 - 0.05$) with a 1 : 1 ratio. Within the segregating lines, 710 plants were classified as resistant and 271 as susceptible which was close to a 3 : 1 ratio ($X^2 = 3.6$, $P = 0.10 - 0.05$).

In the cross Anoidium $\times$ Valentine, the F_1 was resistant, and the observed reactions of the F_2 (Table 5) and of the F_3 progeny rows (Table 6) were in satisfactory agreement with the expected on the basis of a single dominant gene for rust resistance. Among the F_3 progenies classified as segregating, there were 751 resistant and 254 susceptible plants. A X^2 test for goodness of fit to a 3 : 1 ratio gave a value of 0.04, which corresponds to a P value of between 0.50 to 0.70, thus supporting the single factor hypothesis.

Inheritance of Reaction to Race 15B of P. graminis tritici

The reactions to race 15B of F_3 lines from crosses between Montcalm, Valentine and Anoidium were studied in the seedling stage in the greenhouse at low (65 to 70°F.) and high (80 to 85°F.) temperatures. At the low temperature, it was impossible to distinguish differences in reaction between resistant and susceptible material. At the high temperature, there were distinct differences in the reactions of the resistant and susceptible parents (Figure 2). These reactions were used as a basis for classification of the hybrid seedlings. The F_3 lines were classified as homozygous resistant, segregating, or homozygous susceptible.

In the F_3 of Anoidium $\times$ Valentine, 17 lines were classified as resistant, 30 as segregating, and 15 as susceptible. This agreed ($X^2 = 0.27$, $P = 0.90 - 0.80$) with the 1 : 2 : 1 ratio expected on the basis of a single dominant gene. Among the segregating lines, a total of 341 seedlings were classified as resistant and 132 as susceptible. A X^2 test for goodness of fit to a 3 : 1 ratio gave a value of 2.13 which corresponds to a P value of 0.20 to 0.10. Thus, these data indicated that the seedling resistance of Valentine to race 15B of *P. graminis tritici* was controlled by a single dominant gene.

Reactions to race 56 in the field also were obtained for the F_3 lines of Anoidium $\times$ Valentine. Only one line failed to show the same reaction to the two races. It was classified as segregating to race 15B as homozygous resistant to race 56. With this line, in the test for reaction to race 15B, 16 seedlings were classified as resistant and only one as susceptible. This difference may have resulted from misclassification in the greenhouse, or in the field where some susceptible genotypes could have escaped infection. Although the possibility of two closely linked genes is not ruled out, the data suggest that resistance to both races is controlled by the same single dominant factor.

FIGURE 1. Mature plant reactions of parental varieties inoculated with race 56 of *P. graminis tritici* under field conditions.

1. Montcalm—*susceptible*
2. Valentine—*resistant*
3. Anoidium—*susceptible.*

FIGURE 2. Seedling reaction to race 15B of *P. graminis tritici* at a greenhouse temperature of 80°–85°F.
at left—Valentine—*resistant*
at right—Anoidium—*susceptible.*

Linkage Studies

Reactions both to race Vr of *U. nuda* and to race 56 of *P. graminis tritici* were obtained for 189 F_3 lines of Montcalm × Valentine and for 82 backcross progenies of Montcalm × (Montcalm × Valentine). The inheritance of reaction to the two diseases has been discussed previously; the data indicated that resistance to each disease was controlled by a single dominant gene. Using the gene symbols T versus t and Un versus un for resistance versus susceptibility to stem rust and to loose smut respectively, the frequency of F_2 genotypes as determined by the reaction of their F_3 progenies was:

F_2 genotypes	Frequency
TT or Tt, UnUn or Unun	134
TT or Tt, unun	9
tt, UnUn or Unun	6
tt, unun	40

Using the "Product Method" for calculating linkage intensities from F_2 data, a recombination value of 8.1 ± 2.1 per cent was obtained from these data.

The genotypes of the F_1 backcross plants of Montcalm × (Montcalm × Valentine) were determined from the reaction of their progeny to loose smut and stem rust. The observed numbers of parental and recombination genotypes were:

Genotype	Number
Tt Unun	30
tt Unun	5
Tt unun	4
tt unun	43

The recombination value from these data is 10.9 ± 3.3 per cent. The estimates of the recombination value for these two genes obtained from the F_2 and backcross data were combined by taking the weighted average. The combined estimate, from the two sources of data, indicates that the genes in Valentine for rust and loose smut resistance are linked with a recombination value of 9.19 ± 1.79 per cent.

Reactions to stem rust in the field and to race Vr of *U. nuda* were obtained for 71 F_3 lines of Anoidium × Valentine and are shown by phenotypic classes in Table 7. These data were used to test the recombination value calculated from the other crosses. A theoretical ratio was calculated on the basis of the independent segregation of a recessive and a dominant gene for loose smut resistance, the dominant gene being linked in coupling with a dominant gene for stem rust resistance with 9.19 per cent recombination (Table 7). The X^2 of 1.59 obtained, which corresponded to a probability of 0.70 to 0.50, indicated satisfactory agreement between observed and calculated ratios.

TABLE 7.—OBSERVED AND THEORETICAL FREQUENCIES BY REACTION CLASSES FOR STEM RUST AND LOOSE SMUT OF F_3 LINES OF ANOIDIUM × VALENTINE

Loose smut class	Stem rust class	Frequency		X^2
		Observed	Calculated	
Resistant or seg. 13R : 3S or seg. 3R : 1S	Resistant or segregating	52	50.9	.0237
	Susceptible	9	6.8	.7117
Susceptible or seg. 1R : 3S	Resistant or segregating	2	2.3	.0391
	Susceptible	8	11	.8182

Total X^2 = 1.59

DISCUSSION

The tissues through which the infection hyphae of *U. nuda* must penetrate before reaching the ovule are those of the maternal parent and may differ genetically from those of the developing embryo. If resistance is controlled by the genotype of the maternal tissue, then infection in the F_1 of reciprocal crosses between a resistant and a susceptible variety should differ. There also should be no segregation in the F_2. If resistance is determined by the genetic constitution of the developing embryo, there should be no difference in the reaction of F_1 plants from reciprocal crosses and segregation should occur in the F_2 generation. In this study, although reaction of the F_1 from reciprocal crosses between Anoidium and Montcalm was not obtained, the level of infection in the F_2 suggested segregation. The F_1 and F_2 data from all other crosses indicated that resistance to both races of loose smut was conditioned by the genetic constitution of the developing embryo rather than by that of the surrounding floral tissue.

Seed or seedling mortality is common with seed inoculated with loose smut (3, 9, 15, 16). In this investigation mortality was particularly great in the progeny of Montcalm × Anoidium grown in the field from seed inoculated by the partial vacuum method. At least part of this may have resulted from unfavourably dry soil conditions, which existed from the time the seed was planted until 3 weeks later. Many seeds weakened by inoculation may have died during this period. Another possibility was that this material was more sensitive to the inoculation technique than were other crosses. There was some evidence that mortality was selective against certain genotypes. A small but significant correlation was obtained between stand and infection for F_3 lines of Anoidium × Montcalm inoculated with race Vs and grown in the greenhouse. Although a measure of selective mortality was not obtained in the field, the difference in distribution, for reaction to race Vs, of F_3 lines grown in the field and those grown in the greenhouse could be explained on the basis of increased selective mortality against resistant genotypes in the field. No indication of selective mortality was obtained in material inoculated with race Vr.

Data obtained indicate that resistance to race Vr of *U. nuda* is governed by a single dominant gene in the variety Valentine and a single recessive gene in the variety Anoidium. The two genes were found to be independent. The dominant gene for resistance in Valentine is probably the same as that in one of its parents, Trebi. This gene has been assigned the symbol Un by Robertson *et al.* (7). A recessive gene conditioning high resistance to loose smut in barley has not been reported previously. Therefore, in accordance with the recommendations of Robertson *et al.* (7), the next available designation, un 7, is suggested for this gene.

For reaction to race Vs of *U. nuda*, data on F_3 lines of Anoidium × Valentine and backcross progenies of (Anoidium × Valentine) × Valentine grown in the field indicate that the resistance of Anoidium is controlled by a single dominant gene. The reactions of F_3 lines of Anoidium × Montcalm studied in the greenhouse also indicate a single dominant gene for resistance. However, the observed distribution in infection classes of F_3 lines of Montcalm × Anoidium and of backcross progenies of Montcalm × (Anoidium × Montcalm) studied in the field was skewed toward the susceptible side more than expected on the basis of a single dominant gene for resistance. This could be the result of greater mortality of resistant than of susceptible genotypes in the latter two crosses.

Skoropad and Johnson (12) have recently found that the resistance of the variety Jet to a "new" race of *U. nuda*, virulent on the variety Titan, was due to a single dominant gene. It was provisionally designated Un 6. Therefore, although there is evidence that the resistance of Anoidium to race Vs is controlled by a single dominant gene, a definite gene symbol probably should not be assigned until its independence of the Jet gene is established.

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PHYSIOLOGIC RACES OF LEAF RUST OF WHEAT IN CANADA 1931 TO 1955[1]

T. JOHNSON[2]

Plant Pathology Laboratory, Winnipeg, Man.

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ABSTRACT

The distribution of the physiologic races of leaf rust of wheat, *Puccinia triticina* Erikss. (= *P. rubigo-vera* (DC.) Wint. f. sp. *tritici* (Erikss.) Carleton), has followed a distinct pattern in each of the three geographical areas of Canada. The predominant races in Eastern Canada have been 58 and 76; in the Prairie Provinces, 5, 9, 15, 126 and 128; and in British Columbia, 1 and 11.

In the Prairie Provinces, it is clear that the wheat varieties in cultivation at any given time in that area and in adjacent parts of the United States have exercised a powerful influence on the prevalence of races and pathogenic strains of races. During the period 1937 to 1954, when varieties with the type of resistance of Hope and H44-24 were widely grown, it became apparent that these varieties exerted a strong selective action on the rust. This selective action resulted in increasing susceptibility due to the selection of pathogenic strains of certain physiologic races of leaf rust. There is evidence that the new variety Lee is now beginning to exercise a similar selective effect.

The problem of how race identification can best be made to serve the interest of breeding resistant varieties is discussed.

INTRODUCTION

Surveys to determine the identity and distribution of physiologic races of wheat leaf rust were first undertaken in Canada in 1931. Except for two early publications (5, 1) this work has been recorded only in mimeographed reports entitled "*Physiologic Races of Cereal Rusts in Canada*", which have been issued each year since 1944. It is the purpose of the present paper to give a concise account of this work from its beginnings to the present time and to relate it, as far as possible, to the economically important work of producing wheat varieties resistant to leaf rust.

ANNUAL SURVEYS OF DISTRIBUTION OF PHYSIOLOGIC RACES

Race identification in the early years of the surveys was carried out entirely by use of the standard differential hosts, Malakof, Carina, Brevit, Webster, Loros, Mediterranean, Hussar, and Democrat. Race identifications, summarized in Table 1, showed that, although many races were identified, the bulk of the rust was made up of a few races, particularly race 1, the related races 2 and 15, a second pair of related races 9 and 31, and race 76. It soon became evident that these races were distributed unevenly throughout Canada. Races 1 and 11 were prevalent in British Columbia but were rather scarce elsewhere. Race 76 was predominant in Eastern Canada but not in other parts. Certain other races, such as 2 and 15, 9 and 31, and 5 and 52, were rather generally distributed but were concentrated in greatest amount in the Prairie Provinces. The regional distribution of the most frequently collected races or race groups is shown graphically in Figure 1.

[1]Contribution No. 1546 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa.

[2]Officer-in-Charge.

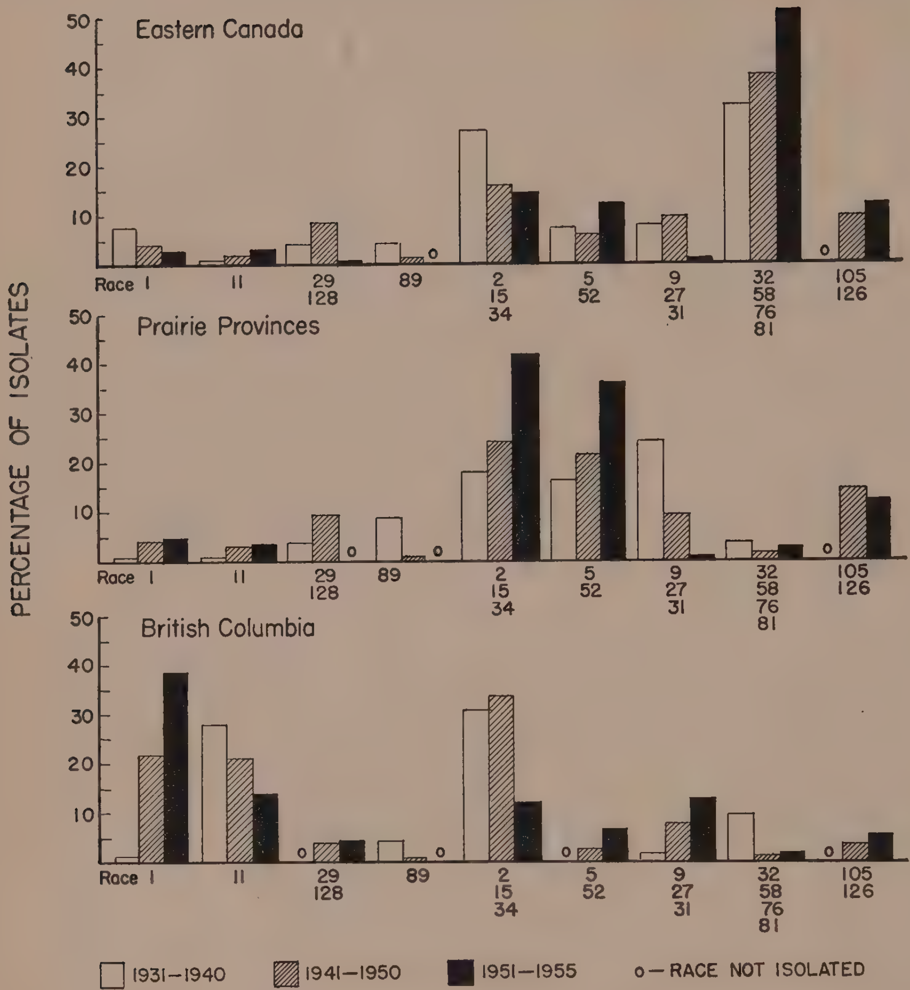

FIGURE 1. Distribution of the principal physiologic races of leaf rust of wheat in Eastern Canada, the Prairie Provinces, and British Columbia during the periods 1931-1940, 1941-1950, and 1951-1955, in per cent of total isolates from each area.

In the course of time it became apparent that certain races either increased or decreased in prevalence. For example, the prevalence of race 1 in British Columbia showed a steady increase during the three arbitrarily selected periods 1931-1940, 1941-1950, 1951-1955 (Figure 1). The race group 9-27-31, prominent in the Prairie Provinces during the first period, has declined almost to extinction in recent years in that area. In the same area, the race groups 2-15-34 and 5-52 have assumed a gradually increasing importance. Occasionally, there have been examples of the appearance and rise to abundance of new races. A pertinent example is the appearance in 1941 of race 126 which has acquired considerable importance in recent years. An example of the gradual disappearance of a race and its replacement by another race only slightly different in patho-

genicity is shown (Table 1) by the apparent replacement of race 76 by race 58 in Eastern Canada about 1947. Because of the similarity of these races they have been grouped as one unit in Figure 1.

PATHOGENICALLY DISTINCT STRAINS WITHIN PHYSIOLOGIC RACES

As long as only the standard differential hosts were used for the identification of races, pathogenic variation was limited to that which could be detected by observing the infection types that developed on these hosts. When it was established that other wheat varieties reacted differently to different cultures of the same race, it became evident that there existed a type of pathogenic variation that could not be detected by means of the standard hosts. That this type of variation might be of great significance was indicated in 1943 when Renown and other H44 or Hope derivatives rusted severely in the experimental plots at Winnipeg. Isolations from Renown showed that the race chiefly responsible for this severe infection was race 15, which had been for several years one of the most widely prevalent races in the Prairie Provinces but had not then shown evidence of any high virulence on Renown. Further studies (1) showed that there were present in races 5 and 15 pathogenic strains highly virulent on H44-24, Hope and certain varieties derived from them. The widespread appearance in the early forties of race 128 was possibly a similar development. As this race could not readily be distinguished from race 29 under greenhouse conditions at Winnipeg, it was regarded as a variant of that race virulent to a number of Hope and H44 derivatives.

To determine which isolates of the various races were virulent in this respect, it became regular practice to employ Hope or Renown as an accessory host with the standard hosts. Although these varieties are not highly satisfactory differential hosts, they nevertheless served to differentiate rust isolates of high and low virulence. Isolates of high virulence produced a 3 type of infection, whereas those of lower virulence ranged in infection type from a 1 type to an X type.

Renown (H44 × Reward), distributed to farmers in 1937, was the first derivative of Hope or H44 to be widely grown in Canada. It was not seriously affected by leaf rust until 1943 when, as stated above, it rusted rather severely at Winnipeg. The leaf-rust percentage readings on this and other wheats derived from Hope and H44, shown graphically in Figure 2, indicate the gradual increase in the leaf-rust infection of these varieties that took place between 1942 and 1948. This increase in percentage readings is probably indicative of a corresponding increase in abundance of rust strains virulent to these varieties. As Hope or Renown did not come into regular use as accessory hosts until 1946, there is no reliable evidence available before that year on the proportion of leaf rust that was virulent to varieties possessing the H44 type of resistance. The curve superimposed on the histogram shows the increase in the percentage of virulent isolates (from the whole of Canada) that occurred between 1946 and 1948. The percentage of virulent and avirulent isolates in races 5, 15, and 126 are shown for the period 1946-1955 in Table 2.

Varieties with leaf-rust resistance derived from H44 or Hope, widely grown in Manitoba and adjacent areas of the United States, became

TABLE 1.—PHYSIOLOGIC RACES OF *Puccinia triticina* COLLECTED ON WHEAT IN CANADA FROM 1931 TO 1955 AND THE NUMBER OF TIMES EACH RACE WAS COLLECTED EACH YEAR

Races	1931	1933	1934	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	Total
1	–	–	–	3	3	1	7	7	10	7	12	11	9	4	7	13	25	23	59	15	5	11	4	236
3	–	–	–	–	–	1	1	4	5	13	9	15	15	18	14	8	2	2	–	3	1	1	3	115
5[1]	3	2	–	4	14	7	22	4	15	9	2	14	11	31	34	42	92	66	82	63	33	96	94	740
6	–	–	–	–	2	–	1	1	4	–	2	–	–	–	–	–	–	–	–	–	–	–	–	10
9[2]	14	4	2	2	7	23	20	7	42	28	32	26	19	20	13	8	9	–	3	3	4	5	6	297
10	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
11	–	–	–	–	3	4	7	6	21	12	1	1	4	1	4	13	17	8	18	9	10	7	10	156
13	3	–	–	–	–	4	–	–	–	1	2	–	–	–	–	–	–	–	–	–	–	–	–	10
14	2	–	–	1	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	5
15[3]	12	6	1	7	16	23	38	28	35	22	34	48	46	86	50	41	71	51	87	81	56	105	106	1050
19	–	–	–	–	3	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	5
20	4	–	–	–	–	–	–	–	6	2	–	–	–	–	–	–	–	–	–	–	–	–	–	12
28	–	–	–	–	2	–	1	–	1	–	2	2	–	–	1	–	–	–	–	–	–	–	–	9
29	–	–	–	–	4	3	11	2	10	11	13	13	14	5	–	–	–	–	–	–	–	–	–	86
30	2	7	–	–	–	2	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12
32	–	3	–	–	1	6	–	10	8	5	–	–	1	–	–	–	–	–	–	–	–	–	–	34
33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	8	10	–	–	–	–	–	19
35	–	1	1	1	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	5	2	5	16
37	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	2
38	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	1	–	–	–	3
39	–	–	–	–	–	–	1	–	3	1	1	–	–	–	–	–	–	–	–	–	–	–	–	6
41	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
42	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
44	1	2	3	–	4	–	–	3	–	2	–	–	–	–	1	5	–	–	–	–	–	–	–	21
50	–	–	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
53	4	1	–	–	1	1	3	1	1	1	–	1	–	–	–	–	–	–	–	–	–	–	–	14
56	5	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
58	–	–	–	–	–	1	11	4	2	3	6	3	7	17	24	23	41	48	67	65	71	65	42	500
62	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
64	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
65	–	–	–	1	3	1	–	–	1	–	–	1	1	1	–	–	–	–	–	–	–	–	–	9
66	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
72	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	2

76	–	–	–	8	6	13	9	14	9	22	12	3	12	27	9	–	–	–	–	–	–	–	–	144
77	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
80	–	–	–	3	1	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	6
81	–	–	–	–	7	3	–	2	–	2	–	–	2	–	–	–	–	–	–	–	–	–	–	16
83	–	–	–	–	–	–	–	1	1	–	–	–	–	–	1	–	–	–	–	–	–	–	–	3
85	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
87	2	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
88	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
89	–	3	–	5	4	3	12	6	9	1	–	–	–	–	–	–	–	–	–	–	–	–	–	43
90	–	–	1	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
93	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	2	3	1	2	2	1	13
101	–	–	–	1	–	–	1	2	–	–	–	2	3	–	–	–	–	–	–	–	–	–	–	9
102	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1
103	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	3
104	–	–	–	–	–	2	1	3	1	2	1	–	1	–	–	–	–	–	–	–	–	–	–	11
113	–	–	–	–	–	–	–	–	–	1	2	–	3	24	–	–	–	–	–	–	–	–	–	30
124	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	–	–	–	–	–	3
126[4]	–	–	–	–	–	–	–	–	2	3	10	10	–	2	31	48	91	60	47	34	6	48	39	431
128	–	–	–	–	–	–	–	–	–	–	–	20	53	34	12	3	4	2	2	2	2	–	–	134
130	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
140	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	3	5
141	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1
143	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1
Total	56	36	10	38	83	100	148	106	190	151	145	170	203	272	201	207	361	275	372	278	195	342	313	4253

[1]Includes the similar race 52.
[2]Includes the similar races 27 and 31.
[3]Includes the similar races 2 and 34.
[4]Includes the similar race 105.

TABLE 2.—PERCENTAGE OF ISOLATES OF STRAINS OF RACES 5, 15, AND 126 AVIRULENT AND VIRULENT TO HOPE AND H44 DERIVATIVES. (EACH FIGURE IS A PERCENTAGE OF TOTAL CANADIAN LEAF-RUST ISOLATES).

Year	Races					
	5	5*a*	15	15*a*	126	126*a*
1946	2.6	8.8	19.8	11.4	0.7	0.0
1947	0.0	16.9	8.4	16.4	1.5	13.9
1948	0.0	20.3	1.9	17.9	1.9	21.2
1949	0.0	25.5	2.5	17.2	1.4	23.8
1950	0.0	24.0	1.1	17.5	8.0	13.8
1951	0.3	21.7	1.3	22.0	4.3	8.2
1952	1.0	21.6	3.2	25.8	7.5	4.7
1953	1.0	15.8	4.1	24.6	3.1	0.0
1954	2.6	25.4	5.0	25.7	8.1	5.8
1955	5.1	24.9	6.7	27.2	2.9	9.6

NOTE.—The suffix *a* indicates a strain virulent to varieties possessing the type of resistance of Hope and H44.

TABLE 3.—PERCENTAGE OF ISOLATES OF CERTAIN LEAF-RUST RACES OBTAINED FROM THE VARIETIES LEE, SELKIRK, THATCHER AND REDMAN IN COMPARISON WITH THE PERCENTAGE OF ISOLATES OF THE SAME RACES IN THE GENERAL SURVEY. (NUMBER OF ISOLATES FROM EACH VARIETY IN PARENTHESES).

Races	Percentage of isolates in collections from				
	Lee (24)	Selkirk (28)	Thatcher (50)	Redman (31)	All varieties (313)
5	8.4	14.3	40.0	54.9	*30.0*
15	45.9	46.4	34.0	29.0	*33.9*
58	8.3	7.1	12.0	0.0	*13.4*
126	37.5	32.1	10.0	3.2	*12.5*
Other races	0.0	0.0	4.0	12.9	*10.2*

susceptible to leaf rust between 1943 and 1948. Effective resistance to leaf rust was again provided to farmers by the variety Lee which was licensed for distribution in Canada in 1950. In tests prior to its distribution this variety had shown a high degree of field resistance. In tests of seedlings in the greenhouse, it had shown high resistance to most races. Exceptions were race 12 to which it proved susceptible in American tests (4) and races 1 and 11 to which it was moderately susceptible in Canadian tests.* The first evidence for the presence in common races of strains virulent to Lee is apparently the discovery in 1951 by Johnston and Levine (3) of several cultures of race 5 that produced relatively severe infection on Lee seedlings.

Lee, which came to be grown on a considerable acreage in Manitoba and eastern Saskatchewan, has generally shown high resistance to leaf rust. However, evidence for the presence in the field of rust strains virulent to Lee came from a study of certain isolates of race 126 obtained from Lee grown in Saskatchewan in 1954. These isolates showed greater virulence to this variety than other isolates of race 126. In 1955, there was further evidence in the same direction, as five isolates of race 126 were

*Unpublished information.

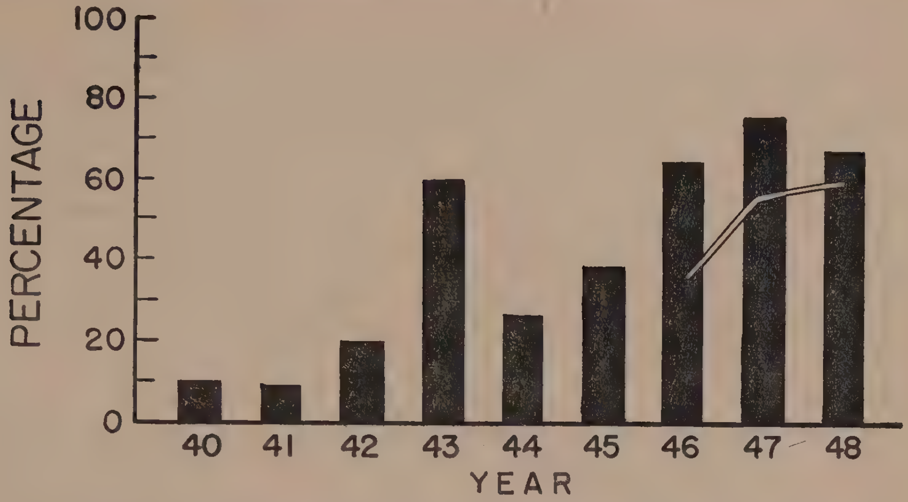

FIGURE 2. Average percentages of leaf rust infection on wheats derived from Hope and H44 as recorded at Winnipeg, 1940 to 1948, shown by columns. The curve shows the frequency of isolates virulent to these varieties in per cent of total Canadian isolates for each year.

found that were highly virulent to Lee. Isolates of high virulence were also found in races 5 and 15.

It appears (Table 3) that Lee shows a tendency to select race 126 and probably also race 15. It is probably significant that 37.5 per cent of the leaf-rust isolates from Lee were race 126 which comprised only 12.5 per cent of all Canadian isolates.

PRESENT METHODS OF DETERMINING LEAF RUST STRAINS

It seems evident that the physiologic races as identified on the standard differential hosts are frequently of less significance in relation to plant breeding material and new rust-resistant varieties than pathogenic variants within these races. It therefore becomes necessary to devise adequate methods for discovering potentially dangerous rust strains and for determining their pathogenic characteristics. Since race identification is done so largely to assure the success of breeding programs for the production of resistant varieties, it is essential to give close consideration to the sources of resistance used.

One way of ascertaining the adequacy of a given resistant variety for breeding purposes is to expose that variety to infection by all rust collections that are studied. The variety would not be a differential host until a strain of rust is found that can attack it vigorously. When such a strain of rust is found, the variety becomes a differential host and a very important one if the variety is a source of resistance in an important breeding program. Obviously, the variety need not become a part of the standard differential-host set by virtue of its capacity to identify rust strains but could be utilized merely as an accessory differential host.

For several years, a number of wheat varieties have been utilized at Winnipeg as accessory hosts or "screening sets". The procedure in the

identification of races is briefly as follows: Each rust collection is initially increased on the susceptible variety Little Club. When infections on this variety are well developed, two single-pustule isolates are established for purposes of race identification. These isolates serve the purpose of random sampling. The remainder of each original culture on Little Club is used to inoculate a screening set composed of varieties that are currently of interest by virtue of their rust reaction. The varietal composition of the screening set is, of course, subject to change from time to time as old sources of resistance become ineffective or as new ones become known. In the last year or two the screening set has been composed of the varieties Lee, Kenya Farmer, Exchange, Gabo, Frontana, and Selkirk.

DISCUSSION

The fluctuations that have taken place in past years in the distribution and prevalence of physiologic races inevitably lead to a consideration of why these changes have occurred. The reasons must be sought in the inherent characteristics of the races. Races conceivably differ in such characteristics as ability to overwinter and, in general, in their responses to environmental conditions such as temperature, light or humidity. Knowledge of such racial characteristics is, at present, too scanty to serve even as a basis for speculation.

Such reasons as can now be given for changes in racial prevalence are derivable chiefly from the known differences in the abilities of races to infect and to multiply on wheat varieties grown in certain regions. Some, though by no means all, of the fluctuations in the abundance of races can be accounted for in this way.

The decline in prevalence of race 9 in the Mississippi Valley in the early 40's appears to be an example of varietal effect on the abundance of a race. Race 9 was the most widely prevalent race in the Great Plains region and the Upper Midwest area of the United States from the early 20's to about 1940 (4). It was obviously very well adapted to the Turkey (including Kharkov) wheats widely grown in the hard red winter wheat area during this period. The replacement of these wheats by Pawnee and other similar varieties from 1942 onwards was evidently one of the chief reasons for the decline in abundance of this race (2). Simultaneously, there was evidence that the widespread growing of Pawnee had greatly favoured the increase of race 126, which first appeared in 1941.

In the hard red spring wheat area, comprising the Upper Midwest States and the adjacent Prairie Provinces, varieties with leaf-rust resistance derived from Hope or H44 were widely grown from about 1937 onwards. The resistance of these varieties to race 9 probably accounts for the fact that this race was less prevalent in the Prairie Provinces than in areas farther south. For several years these varieties displayed a high or moderate resistance to leaf rust. When they began to rust more severely, about 1943, it was clear, as stated elsewhere in this paper, that much of the rust produced on them was caused by pathogenic strains of races that had been widely prevalent in previous years. These pathogenic strains were of particular importance in races 5, 15 and 126, and also in race 29, if race 128 is to be accepted as a pathogenic variant of that race.

Though the prevalence of races may often be explained on the basis of varietal reaction, there are nevertheless instances of the rise or decline in importance of races which are not readily explained in this way. A pertinent example is the rapid decline and virtual disappearance of race 128 from the Prairie Provinces after the period 1944-1947 during which it was among the most important races. As this race was highly pathogenic to the varieties grown in that area there was no obvious reason for its disappearance.

Geographical barriers are among the factors of importance in determining the distribution of races. There are two barriers of this type in Canada: The Rocky Mountains, which separate the province of British Columbia from the Prairie Provinces; and the extensive area of forest and lakes that separates the Prairie Provinces from the arable land of Eastern Canada. To a certain extent, both act as barriers to the spread of leaf-rust races. It is possible that the Rocky Mountains are only partially effective as a barrier. Races 1 and 11, the predominant races of British Columbia, are very rarely found in the eastern parts of the Prairie Provinces but occur frequently in certain years in southern Alberta. As the area in which these races occur is a northward extension into Canada of the winter wheat belt, it is not clear whether the presence of these races is due to air-borne spores carried across the mountains or is merely the result of a northward extension of the rust flora congenial to the winter wheat varieties that are grown in areas just east of the Rocky Mountains.

The Great Lakes and the contiguous forested area no doubt form a rather effective barrier against the distribution of races. This extensive uncultivated region is probably one of the reasons for the scarcity in Western Canada of races 58 and 76 which have long been the characteristic races of Eastern Canada and the adjacent areas in United States.

ACKNOWLEDGEMENTS

Until 1945 the work on which this paper is based was carried out in collaboration with Margaret Newton and since that time in collaboration with A. M. Brown. While the work is theirs as much as his, the writer has not included them as co-authors because both are living at a distance from Winnipeg and, not having read the manuscript, cannot be held accountable for any interpretations of the work expressed in this paper. The writer is indebted to W. E. Clark, Plant Pathology Laboratory, Winnipeg, for the preparation of Figures 1 and 2.

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EXCHANGEABLE CATION CHARACTERISTICS OF SOME WEST CENTRAL ALBERTA SOILS[1]

STEPHEN PAWLUK[2] AND C. F. BENTLEY[3]

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ABSTRACT

Seven soil series of west central Alberta have been studied to determine whether their exchangeable cation characteristics and composition were related to their obvious morphological differences. These soils, developed on the same or very similar parent materials, represent a sequence of profiles progressing from black earth through varying degrees of podzolic degradation to podzolized grey wooded.

Morphological characteristics and some analytical results were closely related. With increasing eluviation the proportion of exchangeable calcium decreased and that of hydrogen increased. Eluviated horizons were low in clay and were associated with B horizons high in clay. Cation exchange capacities were closely correlated with clay plus organic matter contents for all horizons. Lowest pH values were found in the B horizon of profiles with eluviated A_2 horizons, although the percentage base saturation was lower in the A_2 horizons. The proportion of the exchange complex occupied by magnesium, sodium, and potassium remained constant or increased in eluviated horizons. Replenishment by weathering may explain this unexpected condition. Physical and chemical analyses for the podzolized grey wooded profiles indicated that some weathering of minerals in the former grey wooded A_2 horizon had occurred.

Physical and chemical differences in these soils paralleled changes in amount and nature of vegetation, which were attributed primarily to differences in moisture efficiency.

INTRODUCTION

Exchangeable cation characteristics of soil have frequently been related to the pedogenic processes responsible for their development (2, 9, 19). Gedroiz was one of the first to study these relationships (9). He stated that environmental conditions which gave rise to podzolic soil forming processes cause degradation of chernozems. Gedroiz found this degradation was accompanied by changes in the exchangeable cation characteristics of the soils.

West central Alberta did afford an opportunity to study a sequence of soils ranging from well drained black earth to podzolized grey wooded profiles. These soils enabled a more extensive study of exchangeable cation relationships than Gedroiz had made. Successive stages of podzolization were recognized in the sequence although the soils were not exactly comparable to those he used. The black earth and degraded black earth soils of Alberta are quite similar to the Russian soils studied (3, 14). However, typical podzols as described in Russia, Eastern Canada, and the northeastern United States occur very rarely in Alberta. Grey wooded soils have been described by Williams and Bowser (19) and such soils are usually the most severely leached of any in Alberta. They differ from podzols by lacking an organic layer in the B horizon and the acidity common to those soils. Moreover, grey wooded profiles have a distinct textural B horizon. The Alberta sequence includes podzolized grey wooded soils

[1]Contribution from Experimental Farms Service, Canada Department of Agriculture, and Department of Soil Science, University of Alberta, Edmonton, Alta.

[2]Formerly Pedologist, Alberta Soil Survey, Canada Department of Agriculture; now Graduate Student, University of Minnesota, St. Paul, Minn.

[3]Associate Professor of Soil Science.

which have recently been described (14). These soils have a complex sequence of horizons; a new profile is developing in a former grey wooded A_2 horizon. Podzolized grey wooded profiles are more acid in the upper horizons than grey wooded soils. Visual observations suggest a downward movement of iron from the new eluvial horizon. These profiles are more severely leached than grey wooded soils but the new podzol profiles forming in the grey wooded A_2 are usually in the initial stages of development (14).

Sequences involving podzolized grey wooded and podzolized grey brown podzolic soils have been discussed elsewhere. These soils have been described rather recently and the need for a better understanding of the processes involved has been expressed (8, 11).

This investigation was undertaken to study the exchangeable cation characteristics and the composition of the sequence of Alberta soils mentioned. It was desired to determine whether these characteristics were related to their obvious morphological differences and to determine the nature of this relationship, if it existed.

MATERIALS

A study was made of seven soil series selected to represent successive stages of degradation progressing from well drained black earth to podzolized grey wooded profiles. These soils, developed on the same or closely related parent materials, were sampled within the area between Gull Lake, Innisfail, and west to the Rocky Mountains. Descriptions of the soil series follow in order of their occurrence from east to west. Characteristics of the profiles are outlined in Figure 1.

Antler Loam

The Antler series has a black earth profile developed on glacial till derived from the Paskapoo geological formation. Antler soils occur in the well drained position where topography is undulating to hilly. The vegetation is mixed parkland consisting of grass, shrubs, and aspen poplar trees (*Populus tremuloides*). These soils occur at an elevation of about 2,100 feet, where mean annual temperature is 35°F. and total annual precipitation is about 17 inches.

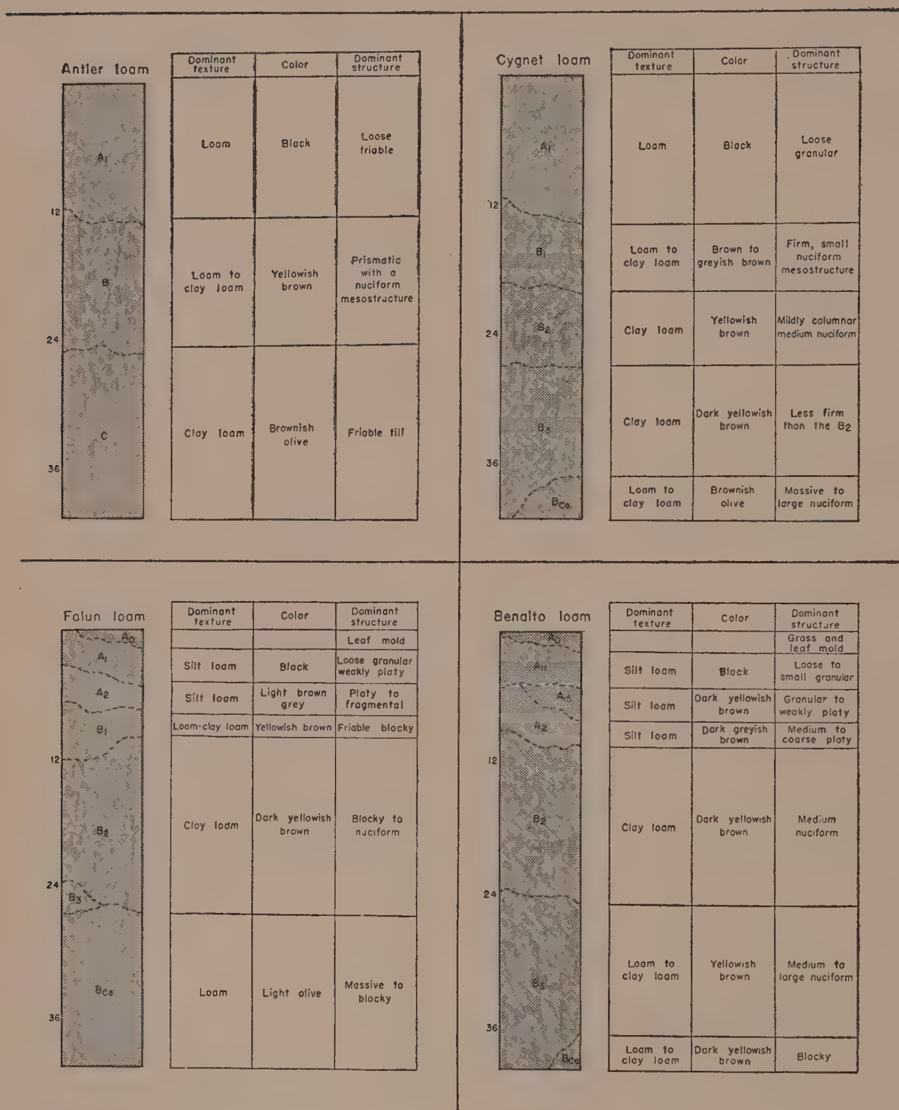
Cygnet Loam

This soil is similar to the Antler series. However, the profile shows slight morphological evidence of podzolic and/or solodic degradation. The surface material shows evidence of sorting and/or wind or water deposition. Vegetation consists of grass, shrubs and light aspen poplar tree cover.

Falun Loam

Falun soils have a grey black earth profile. They occur in the well drained position on glacial till derived predominantly from the Paskapoo formation. Some material from the heavier textured, less calcareous Edmonton formation may be present in the parent material. These soils have a tree cover dominated by aspen and balsam (*Populus tachamahacoa*) poplar with some grass and shrubs. Topography is undulating to gently rolling.

Fig. 1 Profile characteristics of some west central Alberta soils



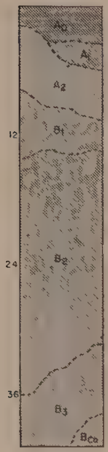
Benalto Loam

This series has a degrading black earth profile and is similar to the Falun series except that the parent material is derived from the Paskapoo formation only.

Breton Loam

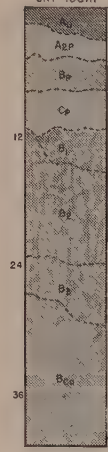
Breton soils have a grey wooded profile. The parent material is glacial till of Paskapoo origin, often quite silicious. The series has undulating to rolling morainal topography. Aspen poplar dominates the vegetation but there are also balsam poplar, spruce (*Picea glauca*) and shrubs.

Breton loam



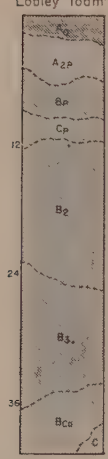
Dominant texture	Color	Dominant structure
		Leaf mat
Silt loam	Dark brown	Loose
Sandy loam	Greyish brown	Platy
Clay loam	Dark yellowish brown	Transition to B_2
Clay loam	Dark yellowish brown	Medium nuciform to blocky
Clay loam	Dark yellowish brown	Medium nuciform less defined than the B_2
Clay loam	Dark yellowish brown	Blocky

Caroline* silt loam



Dominant texture	Color	Dominant structure
		Leaf mat
Silt loam	Pinkish grey	Fine platy to single grain
Silt loam	Strong brown	Fine platy to crumb
Silt loam	Light brownish grey	Medium to coarse platy
Silty clay loam to clay loam	Dark brown	Nuciform to granular
Silty clay loam to silty clay	Dark brown to dark yellowish brown	Fine to medium nuciform
Clay loam to silty clay	Light olive	Nuciform to massive
Clay loam to silty clay loam	Light olive	Blocky

Lobley loam*



Dominant texture	Color	Dominant structure
		Leaf mat
Silt loam	Pinkish grey	Loose
Silt loam	Yellowish brown	Crumb
Silt loam	Light brownish grey	Platy
Clay loam	Dark brown	Nuciform to blocky
Clay loam	Dark brown	Large nuciform to blocky
Loam to clay loam	Light olive	Blocky
Sandy clay loam	Light olive	Massive

*The designations A_{2P}, B_P and C_P represent horizons of micro podzols found in the A horizon of a grey wooded profile.

Color designations are those of the Munsell charts (22) taken for wet soils.

Caroline Silt Loam

The Caroline series has a podzolized grey wooded profile. It has developed in the well drained position on a lacustrine deposit, which overlies glacial till often found within 30 inches of the surface; both materials are of Paskapoo origin. Topography is undulating. Vegetation is dominated by lodgepole pine (*Pinus contorta*) with some aspen poplar.

Lobley Loam

Lobley soils have a podzolized grey wooded profile. The parent material is glacial till. However, this till was deposited by the Cordilleran

glaciation whereas parent materials of the foregoing series were deposited by the Keewatin glaciation. The topography is undulating to rolling. The vegetation is lodgepole pine and a few shrubs. These soils occur at elevations of 3,000-3,500 feet where mean annual temperature is 33°F. and total annual precipitation is about 19 inches.

METHODS

Exchangeable Ion Determinations

The exchangeable cations were removed from air dry soils with neutral 1 N ammonium acetate (18) by the procedure of Bentley and Rost (2). The method of Fieldes *et al.* (7) was used to prepare extracts for analyses. Total cation exchange capacity was determined by Brown's procedure (4) modified to use the centrifuge; a ten-fold dilution of the extract increased the accuracy of the determination. Calcium and magnesium were determined by a modification of the method of Cheng and Bray (5). Exchangeable sodium and potassium were determined by flame photometry employing a Beckman Model DU spectrophotometer and attachments; recovery tests on several unknowns established the suitability of the procedures used.

Additional Physical and Chemical Analyses

Mechanical analyses were carried out according to the modified pipette method outlined by Toogood*. Soil pH was determined using a Beckman Model N 2 pH meter and a soil paste as described by Doughty (6). Carbon was determined by the dry combustion process described by Winters (20). Nitrogen was determined by the Kjeldahl-Wilfarth-Gunning method (1). Total analyses were done by the procedure of Robinson (17). Results for carbon, nitrogen and fusion analyses are expressed on the oven-dry basis.

RESULTS AND DISCUSSION

Analytical results presented in Tables 1 and 2 are averages for two profiles of each named soil series. These data are presented as averages because data for the two profiles of each series were so very similar. The fusion analyses and molecular ratios calculated from them in Table 3 are for one profile of each series.

The results of the mechanical analyses were interesting. Eluviated horizons were lower in clay and were associated with B horizons higher in clay than corresponding horizons in less eluviated soils. Progressive degradation was reflected by an increase in the thickness of the A_2 horizon proceeding from the Cygnet to the Lobley series. In the podzolized grey wooded profiles there was a higher per cent of clay in the A_{2p} and B_p horizons than in the C_p. These horizons were all found in the former grey wooded profile's A_2 horizon. It may be that, during formation of the podzolized grey wooded A and B horizons, some particles of sand and silt have weathered in situ to form clay. The data of Table 3 support this suggestion and similar results have been reported elsewhere (10).

The total cation exchange capacity by summation was frequently greater than by direct determination. These differences were usually

*Toogood, J.A. Modified pipette method for mechanical analysis. *Unpublished procedure.* Univ. of Alberta. 1953.

TABLE 1.—MECHANICAL COMPOSITION, NITROGEN AND ORGANIC CONTENT OF SOILS (means of duplicate profiles)

Series and horizons**		Sand %	Silt %	Clay %	Nitrogen %	Organic carbon %
Antler	A	40	40	20	0.50	4.8
	B	39	35	26	0.10	1.0
	C	31	42	27	—	—
Cygnet	A_1	28	50	22	0.30	4.2
	B_1	32	41	27	0.07	1.1
	B_2	31	38	31	0.08	0.7
	B_3	36	32	32	—	—
	B_{ca}	36	36	28	—	—
Falun	A_1	44	47	9	0.78	3.8
	A_2	47	43	10	0.05	0.3
	B_1	45	30	25	0.06	0.4
	B_2	46	26	28	0.05	0.5
	B_{ca}	42	43	15	—	—
Benalto	A_{11}	28	55	17	0.66	7.8
	A_{15}*	29	53	18	0.10	1.6
	A_2	30	53	17	0.08	0.7
	B_2	32	41	27	0.06	0.5
	B_3	32	42	26	—	—
	B_{ca}	38	40	22	—	—
Breton	A_1	23	55	22	1.37	12.1
	A_2	45	46	9	0.05	0.5
	B_1	42	30	28	0.05	0.6
	B_2	42	28	30	0.05	0.6
	B_3	37	32	31	—	—
	B_{ca}	36	36	28	—	—
Caroline	A_{2p}	26	5	9	0.08	0.8
	B_p	23	67	10	0.08	0.7
	C_p	26	66	8	0.10	0.3
	B_1	19	45	36	0.03	0.4
	B_2	27	32	41	0.04	0.4
	B_3	20	37	43	—	—
	B_{ca}	21	50	29	—	—
Lobley	A_{2p}	35	54	11	0.07	0.6
	B_p	38	48	14	0.05	0.7
	C_p	45	48	7	0.03	0.3
	B_2	37	29	34	0.04	0.5
	B_3	33	37	30	0.04	—
	B_{ca}	50	33	17	—	—

*Characteristics of this horizon are intermediate between those of A_1 and A_2.
**See Figure 1 for approximate thickness of horizons.

greatest for the B_{ca} horizons where they were probably due to solution of calcium carbonate and calcium bicarbonate in the ammonium acetate used for the extraction of exchangeable cations. For other horizons the differences were not greater than for similar data reported elsewhere (16, 2).

Exchange characteristics differed between the soil series. The most striking difference was in the exchangeable calcium. Increasing eluviation, reflecting a greater degree of podzolization, was accompanied by a reduction in the per cent base saturation. Exchangeable hydrogen increased as

TABLE 2.—REACTION AND EXCHANGEABLE CATION PROPERTIES
(means of duplicate profiles)

Series and horizons		Percentages of exchangeable cations*						Cation exchange capacity**	
		pH	H	Ca	Mg	K	Na	Calculated	Determined
Antler	A	6.8	2.2	82.6	12.7	1.9	0.6	32.3	34.1
	B	6.5	1.6	84.9	11.5	1.3	0.6	31.2	26.1
	C	7.9	0.0	86.6	12.4	0.5	0.5	38.2	25.7
Cygnet	A_1	5.9	10.5	76.2	7.7	4.7	0.9	34.4	30.3
	B_1	5.5	9.5	75.9	11.3	1.8	1.5	27.4	23.2
	B_2	5.7	5.7	78.9	11.4	2.0	2.0	24.6	21.5
	B_3	5.8	4.4	77.1	14.5	2.0	2.0	24.9	22.5
	B_{ca}	7.7	0.0	90.3	7.8	0.8	1.1	37.0	20.4
Falun	A_1	6.3	9.6	78.3	8.0	3.0	1.1	36.3	37.8
	A_2	6.2	12.1	67.7	15.2	3.0	2.0	9.9	9.9
	B_1	5.4	10.7	67.5	17.7	2.3	1.8	16.9	15.0
	B_2	5.1	10.5	69.6	16.1	1.9	1.9	21.1	20.1
	B_{ca}	7.6	0.0	81.2	16.2	1.3	1.3	22.9	16.3
Benalto	A_{11}	6.1	6.9	81.6	8.2	2.6	0.7	53.8	53.8
	A_{15}	5.9	11.4	75.1	9.3	2.6	1.6	19.3	17.9
	A_2	5.8	9.0	72.4	13.1	3.4	2.1	14.5	16.2
	B_2	5.6	7.3	71.7	17.4	2.3	1.3	21.9	22.1
	B_3	5.4	6.9	76.3	14.2	1.5	1.1	27.4	24.1
	B_{ca}	7.5	0.0	91.0	6.9	1.2	0.9	33.2	21.5
Breton	A_1	6.5	5.2	83.7	8.6	1.8	0.7	65.1	58.5
	A_2	5.8	20.8	52.1	19.8	6.3	1.0	9.6	14.9
	B_1	5.6	4.6	74.0	17.8	2.7	0.9	21.9	23.7
	B_2	4.8	12.6	71.1	13.7	1.9	0.7	27.0	26.2
	B_3	5.3	10.2	75.2	11.4	2.0	1.2	24.6	23.3
	B_{ca}	7.3	0.0	81.8	14.9	2.0	1.3	29.6	21.1
Caroline	A_{2p}	5.4	19.0	60.3	15.5	3.4	1.8	11.6	11.3
	B_p	5.7	26.2	51.6	7.9	12.7	1.6	12.6	11.8
	C_p	5.5	12.8	65.0	13.7	7.6	0.9	11.7	9.8
	B_1	5.2	5.2	76.6	14.2	3.1	0.9	32.5	27.3
	B_2	5.2	9.0	75.0	12.7	2.2	1.1	26.8	23.7
	B_3	5.3	7.1	73.4	15.2	3.0	1.3	29.7	27.2
	B_{ca}	7.4	0.0	87.1	11.1	1.0	0.8	40.4	30.1
Lobley	A_{2p}	5.4	29.7	52.7	11.0	3.3	3.3	9.1	8.9
	B_p	5.7	25.8	54.8	11.4	4.0	4.0	12.4	12.4
	C_p	5.7	23.6	58.4	14.7	2.2	1.1	8.9	7.2
	B_2	5.2	15.7	64.6	17.0	1.4	1.3	22.3	21.2
	B_3	5.8	6.5	72.0	19.0	0.8	1.7	23.2	23.7
	B_{ca}	7.8	0.0	88.0	10.1	0.8	1.1	37.5	26.0

* Percentages are based on calculated cation exchange capacities.
**Milliequivalents per 100 gm. soil.

calcium decreased. However, calcium remained the dominant exchangeable ion in all horizons reaching a minimum of about 52 per cent saturation in the most severely eluviated horizons.

Increases in exchangeable hydrogen are generally accompanied by decreases in pH. However, in the present investigation the per cent hydrogen saturation was usually highest in the A_2 horizon while the pH was lowest in the B horizon. This is contrary to what would be expected, even though the B horizon had the larger total amount of exchangeable

TABLE 3.—CHEMICAL COMPOSITION AND SOME MOLECULAR RATIOS OF SOILS (data for single profiles)

Series and horizons	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	SiO_2/ Al_2O_3	SiO_2/ Fe_2O_3	Fe_2O_3/ Al_2O_3
Antler A	69.9	2.7	10.9	1.0	0.7	10.9	68.9	0.16
B	76.9	3.0	12.8	0.6	0.8	10.2	68.1	0.15
C	65.6	2.5	11.9	7.0	1.6	9.4	70.0	0.13
Cygnet A_1	67.6	3.5	11.5	1.5	1.3	10.0	51.4	0.19
B_1	69.8	3.9	11.7	1.4	0.8	10.1	47.6	0.21
B_2	74.3	4.1	12.3	1.0	0.8	10.3	48.1	0.21
B_3	72.8	4.5	12.9	1.1	0.9	9.6	43.0	0.22
B_{ca}	67.4	3.8	10.8	5.7	1.0	10.7	47.1	0.22
Falun A_2	78.5	3.1	9.2	0.6	0.7	14.5	67.4	0.22
B_1	78.1	3.4	10.0	0.7	0.8	13.2	61.0	0.22
B_2	71.6	4.9	12.9	0.9	1.1	9.4	38.8	0.24
B_{ca}	75.2	3.6	10.7	1.7	1.1	11.9	55.6	0.21
Benalto A_{11}	42.5	2.1	7.6	3.0	0.6	9.5	53.6	0.18
A_{15}*	73.0	3.3	12.2	0.9	0.7	10.2	58.7	0.17
A_2	74.1	3.4	12.0	0.9	0.7	10.5	57.9	0.18
B_2	73.7	4.7	12.6	1.1	0.9	9.9	41.7	0.24
B_3	68.9	5.0	14.9	1.4	1.1	7.8	36.6	0.21
B_{ca}	63.4	4.5	13.0	6.4	1.3	8.3	37.4	0.22
Breton A_1	44.4	1.6	6.6	3.0	0.4	11.4	73.9	0.15
A_2	79.5	2.3	9.9	0.8	0.6	13.6	91.9	0.15
B_1	77.6	3.4	11.0	0.6	0.6	12.0	60.7	0.20
B_2	76.5	3.3	10.8	0.6	0.6	12.0	61.5	0.20
B_3	75.2	3.8	12.1	0.8	0.7	10.6	52.6	0.20
B_{ca}	67.6	3.8	13.5	3.2	1.1	8.5	47.3	0.18
Caroline A_{2p}	73.4	2.2	10.9	0.8	0.4	11.4	88.6	0.13
B_p	70.8	3.2	16.0	0.7	0.5	7.5	59.0	0.13
C_p	80.1	2.4	10.7	0.5	0.4	12.7	88.9	0.14
B_1	73.7	3.6	12.9	0.5	0.7	9.7	54.5	0.18
B_2	72.5	3.9	13.9	0.9	0.8	8.8	49.5	0.18
B_3	71.8	3.9	15.3	1.0	0.9	8.0	49.0	0.16
B_{ca}	70.3	4.3	15.4	1.0	1.0	7.7	43.5	0.18
Lobley A_{2p}	77.3	1.8	11.3	1.3	1.6	11.6	113.9	0.10
B_p	76.3	3.3	11.5	0.8	0.9	11.3	61.4	0.18
C_p	79.9	2.7	10 2	0.5	0.7	13.3	78.7	0.17
B_2	71.1	4.6	13.1	0.8	1.1	9.2	41.1	0.22
B_3	71.9	4.6	13.6	1.3	1.4	9.0	41.6	0.22
B_{ca}	68.4	3.8	11.4	5.4	1.9	10.2	47.9	0.21

*Characteristics of this horizon are intermediate between those of A_1 and A_2.

hydrogen. This situation may be the result of differences in hydrogen activity, due to variations in the size and nature of the exchange complexes in the various horizons. However, it is typical for Alberta grey wooded soils to have the lowest pH in the B_1 or B_2 horizons (3).

The proportion of some exchangeable metallic cations did not decrease with eluviation. The portion of the exchange complex occupied by magnesium remained fairly constant, increasing or decreasing slightly in eluviated horizons. Sodium and, to a much greater extent, potassium usually increased in per cent saturation in the eluviated horizons. This may be due to weathering of primary minerals and/or to a transformation of clays as suggested by Lyon *et al.* (10).

Statistically, the total cation exchange capacities of these soils were found to have a highly significant relationship to their clay and organic matter contents. Figures for clay content plus five times the organic matter content were compared statistically with the total cation exchange capacities as determined by distillation. An "r" value of +0.490 was obtained. Values of r for 5 per cent and 1 per cent levels of significance are 0.325 and 0.418, respectively. Since most of these samples were low in their organic matter content, this relationship suggests that there is no great difference in the exchange capacity of clays in the eluviated and illuviated horizons. Mineralogically clays in these horizons are probably at least similar.

The data of Tables 1, 2, and 3 show definite differences with progression through the sequence of profiles. Since six of the seven soils were developed on the same or very similar parent materials, considered to be of the same age, profile variations were attributed to differences in type and intensity of soil forming processes. The slight increase in precipitation and increased moisture efficiency have resulted in a change from grass to a predominantly coniferous forest and in deeper leaching of carbonates. Antler, and perhaps Cygnet, soils have developed under the influence of the calcification process. The other soils of the sequence have resulted from increasingly intense podzolic processes.

Several trends were related to the more intense leaching and weathering which resulted in increased depth of solum:

1. There was less organic matter in the A horizon.

2. There was increased acidity in the A and upper B horizons. This was accompanied by a reduction in the percentage base saturation in these horizons.

3. Intense leaching resulted in a lower clay content in the A horizon and clay accumulation in the B horizon.

4. Cation exchange capacity was lower in the A_2 horizons and higher in the B horizons when leaching had been more intense.

5. The molecular ratios of Table 3 were more variable within the more intensely leached profiles. Increased acidity and leaching caused more weathering of minerals.

Processes responsible for the development of podzolized grey wooded profiles have had definite effects on the minerals in the former A_2 horizon. Clay, iron, and, to a lesser extent, aluminum have accumulated in the B_p.

A study of Matthews *et al.* (11) dealt with a sequence involving some of the same Great Soil Groups as the present report. The Alberta sequence involved more soils and a greater range in characteristics but there were distinct similarities for corresponding soils. Chemical composition, exchange characteristics and particle size distribution all showed that the podzolized grey wooded profiles of this study were more intensely developed than the Blanche soil reported by Matthews *et al.* The chemical composition and mechanical analysis data suggested there was more uniformity in the parent materials of the Alberta soils than in the Ontario ones.

The data of this report were in agreement with the morphological differences observed in these soils. There were changes in physical and chemical composition paralleling the increased eluviation encountered

with westward progression through the soil sequence. These data are in accord with the results of Matthews *et al.* (11) and McCaleb and Cline (12) who have reported that the leaching downward of carbonate followed by depletion of bases and the development of acidity contributed greatly to profile development.

It is notable that the soils in this study have developed on rather uniform parent materials of similar age and in an area with relatively little variation in precipitation. Differences in moisture efficiency and the resulting gradual changes in amount and kind of vegetation appeared to be the principal causes of this soil sequence.

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GENETIC AND SEASONAL VARIATION IN INCIDENCE OF BLOOD AND MEAT SPOTS IN CHICKEN EGGS

A. S. Johnson

Canada Department of Agriculture, Ottawa.

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ABSTRACT

The percentages of blood spots in eggs from White Leghorn and Barred Rock pullets, and of meat spots in eggs from Barred Rock pullets, were determined monthly from November to August. About 23,000 eggs were broken in obtaining the data. There was a similar seasonal trend in the case of each type of inclusion, the percentages increasing gradually until late spring. Heritability estimates of blood spot incidence were higher in White Leghorns than in Barred Rocks, averaging .211 and .066 in the two breeds respectively. The heritability of meat spot incidence in Barred Rocks was about .250. Evidence was presented which further indicates that these two types of inclusions are different entities.

The magnitude of genetic differences in frequency of blood spot occurrence has been brought out in various reports, as reviewed by Lerner, Taylor and Lowry (9). These authors selected for high blood spot incidence in a line of White Leghorns over a period of 10 years, resulting in an average level of 22.8 per cent, as observed by candling, compared with 1.4 per cent in the line from which it originated. Their estimate of the heritability of blood spot incidence was .50, whereas Farnsworth and Nordskog (1) obtained a similar estimate for candled eggs of .32.

No estimates of the heritability of meat spot incidence were found in the literature. King and Hall (5) observed, from the New York Random Sample Test results, that the differences among heavy breeds in percentage of meat spots were not significant. Selection for high and low levels of meat spots by Walker at the Massachussetts Experiment Station (reviewed by Merritt, 10) resulted in an increase in the frequency of all meat spots in the high line and a decrease in large meat spots in the low line, although there was no decrease in total number in the latter line.

Seasonal effects on the occurrence of blood and meat spots have been observed. Lerner and Smith (7), Lerner and Taylor (8) and Sauter, Stadelman and Carver (13) were in reasonable agreement that the incidence was low in the early period of production and increased thereafter. A similar slight, though non-significant, seasonal effect occurred in the data of King and Hall (5). Jeffrey (2), on the other hand, found that, in his data, blood and meat spots were most frequent in November.

According to Nalbandov and Card (11) coloured meat spots are degenerated blood spots, whereas Jeffrey and Walker (3), Merritt (10) and Stadelman, Jensen and Cyrus (15) presented evidence to indicate the independence of these two types of inclusions. It has been pointed out by Merritt (10) that there is some inconsistency among reports as to the levels of meat spots occurring in different breeds, particularly in White Leghorns. Nalbandov and Card (12) reported 12.8 per cent coloured meat spots in White Leghorn eggs examined by them, as compared with

[1]Contribution from the Poultry Division, Experimental Farms Service.

6.1 per cent in eggs from heavy breeds, whereas most other workers have found the frequency of occurrence of this inclusion in white-shelled eggs to be negligible (3, 5, 15).

Further information on genetic and seasonal variation of blood and meat spots will be presented in this report.

MATERIAL AND METHODS

The data were obtained during the course of measuring albumen quality of eggs from White Leghorns and Barred Rocks in 1948-49. Full details of the procedure were given by Johnson and Merritt (4). The two flocks were of similar size (452 White Leghorns and 526 Barred Rocks were housed), each being the progeny of 11 sires and 8 to 9 dams per sire. A maximum of 5 eggs per hen per month was broken within the 10-month period, or a total of about 23,000 eggs. The eggs were broken within 2 hours after oviposition and the presence of blood spots in the eggs of both breeds and meat spots in the Barred Rock eggs was recorded, without details of numbers of spots or their size within each egg. Those inclusions which had the bright red appearance of fresh blood were classified as blood spots, whereas any which had a brownish colour were recorded as meat spots. No record of white meat spots in the White Leghorn eggs was made; the number of coloured meat spots in the eggs from this flock was negligible.

For the purposes of analyses, the data were combined into five 2-month periods and the percentages were transformed to angles for variance analysis (Snedecor, 14). Heritability estimates were calculated from variance components, using the combined sire and dam components in estimating the genetic variance (6).

RESULTS AND DISCUSSION

The blood spot percentages were higher in the White Leghorns than in the Barred Rocks (Table 1), agreeing with the observation of King and Hall (5) that heavy breeds have a lower incidence than White Leghorns. There was a distinct seasonal trend, the frequency being lowest in Period 1 and increasing to Period 3 for the Barred Rocks and Period 4 in the case of the White Leghorns. This trend was similar to that observed by Sauter *et al.* (13). King and Hall (5) did not find a significant seasonal trend in their results.

TABLE 1.—SEASONAL INCIDENCE OF BLOOD AND MEAT SPOTS (IN PER CENT)

Inclusion	Breed	Period				
		1 Nov.-Dec.	2 Jan.-Feb.	3 Mar.-Apr.	4 May-June	5 July-Aug.
Blood spots	W.L.	1.93	4.67	8.07	13.79	12.52
	B.R.	2.08	3.56	5.28	8.31	5.81
Meat spots	B.R.	5.85	13.92	25.02	23.83	25.21

TABLE 2.—HERITABILITY ESTIMATES OF BLOOD AND MEAT SPOT INCIDENCE

Inclusion	Breed	Period 1 Nov.-Dec.	2 Jan.-Feb.	3 Mar.-Apr.	4 May-June	5 July-Aug.	Mean*
Blood spots	W.L.	.147	.116	.203	.224	.366	.211
	B.R.	−.012	−.032	.264	.063	.046	.066
Meat spots	B.R.	.155	.244	.328	.249	.275	.250

*Unweighted mean.

The heritability estimates of blood spot incidence in the White Leghorns increased gradually as the percentage increased (Table 2), reaching a level of .366 in Period 5, which is similar to the estimate obtained by Farnsworth and Nordskog (1). Estimates of heritability of this defect in the Barred Rocks were much lower than in the White Leghorns, except for the one for Period 3, the relative magnitude of which is unexplained. There is some indication from the data that heritability increases as the percentage of inclusions increases. There was, in all cases, reasonable agreement between the sire and dam components of variance. The heritability estimates of incidence of meat spots in the Barred Rocks were as high as, or higher than, those for blood spots in the White Leghorns. This observation is in accord with the finding at the Massachussetts Experiment Station that selection can influence the tendency to produce meat spots in eggs, in breeds in which this defect is common.

There is an increasing amount of evidence to indicate that blood spots and meat spots in eggs are of different origin. Such evidence as the relative absence of coloured meat spots in white-shelled eggs (3, 9) and the correlation between shell colour and meat spots (15) seems to require a different explanation than that all coloured meat spots are degenerated blood spots (12). If the latter were the case, then, among breeds of chickens characterized by a relatively high incidence of coloured meat spots, such as Barred Rocks, the ratio of blood spots to meat spots should be the same among different genetic groups, within the limits of chance. If, however, each type of inclusion is due to different genetic causes, then the frequency of one might

TABLE 3.—ANALYSIS OF VARIANCE OF RATIOS OF BLOOD TO MEAT SPOTS IN BARRED ROCKS

Source	D.F.	M.S.
Among sires	10	.1078*
Among months	4	.0795
Error	40	.0354

*Significant at 1% probability level.

be expected to be more or less independent of that of the other. Examination of the data showed marked differences among sire groups in the proportions of these inclusions. For example, the daughters of one sire had 4.1 times as many blood spots but only .59 times as many meat spots as those of another sire. An analysis of variance of these ratios showed a significant difference between sires (Table 3). This further supports the theory that these inclusions are distinctly different entities.

ACKNOWLEDGEMENT

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CHEMICAL PROPERTIES OF SOUTHERN ONTARIO SOILS[1]

K. N. JEYASEELAN[2] AND B. C. MATTHEWS[3]

Ontario Agricultural College, Guelph, Ontario

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ABSTRACT

Statistical analyses of chemical and physical data on 643 surface soil samples showed that (1) the variation in properties was greater between series than within a single series and (2) the variation was greater between than within great soil groups. It was found that with variation in soil texture from sand to clay there was an increase in the average cation exchange capacity, exchangeable potassium content and organic matter content. It was concluded that a series or great soil group does in fact represent a discrete portion of the soil population and it has meaning in terms of chemical and physical properties of the surface soils.

One of the purposes of soil classification is to arrange soils into groups that have some degree of homogeneity in their characteristics. Of necessity, the field classification of soils is based on morphological features that can be seen or measured readily. Although an observable soil feature, such as texture, has a direct influence on crop growth, there are many non-observable properties, such as reaction, exchangeable cations and available phosphorus content that are important in determining the productivity of soils. The agronomic significance of a soil classification system depends on the degree of correlation that exists between the observable morphological characteristics used to differentiate at a given level of abstraction and the associated characteristics that affect plant growth.

The primary purpose of this study was to summarize the information on the chemical and physical properties of some Ontario soils and to determine the differences that exist among different soil series and great soil groups. Such information should be a useful guide in evaluating Ontario soils although the averages given for any series may not apply precisely to any specific area of that soil.

Some investigators have shown that the chemical properties of surface soils are a reflection of management under cultivation. Phosphorus accumulation in potato soils of the Atlantic and Gulf Coast has been reported by Blair and Prince (1), and Cummings *et al.* (2). In North Carolina, McCollum and McCaleb (4) showed that in cultivated soils, most of the differences in organic matter content, pH, and available calcium and magnesium could be attributed to variation between series and there was little evidence that these properties had been differently affected by management practices.

MATERIALS AND METHODS

During the soil survey in Ontario, a large number of samples of surface soils of different soil types have been collected. The majority of the samples were taken from permanent pasture fields in order to avoid dif-

[1]Contribution from Department of Soils, taken from thesis submitted by the senior author to the Graduate School, University of Toronto in partial fulfilment of the requirements for Master of Science in Agriculture.

[2]Graduate student on leave from Government of Ceylon under Colombo Plan Scholarship program of Government of Canada.

[3]Professor of Soils.

TABLE 1.—MEAN VALUES OF SELECTED PROPERTIES OF SURFACE SOILS OF GREAT SOIL GROUPS IN SOUTHERN ONTARIO

Great soil group	Number of samples	Sand	Silt	Clay	pH	Cation exchange capacity	Available P_2O_5	Exchangeable cations			Organic matter
								K	Ca	Mg	
		%	%	%		m.e./100gm.	lb./ac.	m.e./100gm.	m.e./100gm.	m.e./100gm.	%
Brown Forest[1]	141	39.0	39.9	21.1	7.2	22.96	189	0.235	24.6	4.3	6.57
Grey-Brown Podzolic[2]	391	42.3	39.3	18.4	6.8	17.03	102	0.205	17.5	4.3	4.72
Podzol[3]	24	76.8	18.3	4.9	6.1	11.64	69	0.121	6.2	2.2	3.78
Ground-Water Podzol[4]	22	69.6	25.4	5.0	5.9	11.01	59	0.132	7.5	1.3	5.84
Dark Grey Gleisolic[5]	171	37.4	36.5	26.1	6.8	28.32	230	0.276	26.6	5.5	7.85

Series included and number of samples of each:

[1]Dunedin 4, Eamer 4, Elderslie 10, Emily 3, Farmington 7, Grenville 23, Harkaway 10, Hillier 5, Kemble 6, Matilda 8, Morrisburg 9, Osprey 9, Otonabee 8, Sargent 3, Saugeen 5, Sullivan 4, Vincent 8, Wiarton 7, Wolford 8.

[2]Ameliasburg 7, Berrien 18, Bondhead 6, Bookton 4, Brady 4, Brighton 16, Brockport 1, Burford 12, Caledon 6, Caistor 10, Carp 4, Castor 5, Chinguacousy 16, Darlington 7, Donnybrook 9, Dumfries 9, Dundonald 4, Elmbrook 7, Fox 5, Guerin 2, Harriston 39, Huron 26, Kars 7, King 4, Leith 2, Listowel 29, Milliken 4, Oneida 3, Peel 4, Percy 5, Perth 36, Pike Lake 7, Pontypool 15, Schomberg 1, Smithfield 1, South Bay 10, Tecumseth 5, Teeswater 5, Tuscola 7, Waterloo 8, Waupoos 4, Whitby 1, Woburn 2.

[3]Manotick 5, Mountain 1, Sebright 6, St. Thomas 5, Uplands 7.

[4]L'Achigan 10, Gamebridge 3, Rubicon 9.

[5]Bearbrook 8, Brookston 53, Chesley 5, Clyde 1, Colwood 4, Gerow 3, Gilford 3, Granby 14, Jeddo 1, Lily 3, Lovering 6, Lyons 1, Malton 1, Marionville 5, Monck 2, North Gower 10, Osgoode 14, Osnabruck 2, Parkhill 13, Simcoe 3, Ste. Rosalie 1, Toledo 14, Wauseon 4.

TABLE 2.—MEAN VALUES OF SOME CHARACTERISTICS OF SURFACE SOILS, ACCORDING TO TEXTURAL CLASS

Textural class	Number of samples	Sand	Silt	Clay	Cation exchange capacity	Available P_2O_5	Exchangeable cations			Organic matter
							K	Ca	Mg	
		%	%	%	m.e./100gm.	lb./ac.	m.e./100gm.	m.e./100gm.	m.e./100gm.	%
Sand	6	89.2	7.5	3.3	4.8	49	0.08	2.5	1.5	2.1
Loamy sand	49	81.1	14.5	4.4	10.0	62	0.10	7.6	2.0	3.9
Sandy loam	144	64.1	25.8	10.0	15.7	125	0.14	16.3	3.4	5.3
Loam	242	39.8	41.4	18.8	20.6	139	0.21	22.4	4.6	5.8
Silt loam	134	27.7	55.3	21.9	21.9	133	0.22	21.6	5.5	6.3
Sandy clay loam	8	52.4	25.2	22.4	21.0	173	0.19	23.1	4.4	6.1
Silty clay loam	11	18.0	47.9	34.1	27.1	207	0.37	22.5	4.8	5.5
Clay loam	109	29.3	37.9	32.8	26.4	208	0.30	24.7	4.8	6.5
Clay	51	19.9	32.4	47.7	30.0	228	0.48	24.1	6.1	6.7

ferences due to management. Particle size distribution, organic matter, pH, cation exchange capacity, exchangeable calcium, magnesium, and potassium content, and available phosphorus content have been determined on these samples and are reported in the published soil survey reports (6). Seven hundred and forty-nine samples on which the above analyses had been made by similar methods were selected for this study. The samples were taken originally from the following Counties—Bruce, Dundas, Essex, Grenville, Grey, Huron, Perth, Peel, Stormont, and Prince Edward.

To facilitate handling of the data, I.B.M. punch cards were used. The data were statistically evaluated on the basis of series and great soil groups. Mean values for all characteristics for each soil series were also calculated but are not reported here.

RESULTS

The analytical data for the 749 surface soil samples taken during the Ontario soil survey have been compiled and mean values for the soil series are reported elsewhere (3). The mean values of the selected properties for the great soil groups are shown in Table 1. It is evident that in Ontario the Podzol surface soils, on the average, are coarse in texture and have a lower cation exchange capacity, exchangeable cation content, and organic matter content than soils of the other great soil groups. Soils of the Dark Grey Gleisolic great soil group have the highest organic matter and clay content and consequently the highest cation exchange capacity. The mean values for the soils grouped on the basis of textural class, irrespective of great soil group, are shown in Table 2. It is evident that although the 749 samples were taken from soils of widely different profile morphology, different natural drainage and from widely separated regions in Ontario, there was a general increase in cation exchange capacity, exchangeable potassium, calcium and magnesium, available phosphorus and organic matter content with decreasing particle size.

Correlation Studies

The correlation of chemical properties with physical properties that can be observed in the field facilitates general evaluation of the productivity of soils without the necessity of time-consuming laboratory analyses. The correlation of clay and organic matter content with selected chemical properties for 643 soil samples is shown in Table 3. Soil series for which

TABLE 3.—CORRELATION OF CLAY AND ORGANIC MATTER CONTENT WITH CHEMICAL PROPERTIES OF SURFACE SOILS

Chemical property	*Correlation coefficient (r)* *Clay content*	*Organic matter content*
Cation exchange capacity	0.511**	0.840**
Exchangeable calcium	0.310**	0.656**
Exchangeable magnesium	0.312**	0.226**
Exchangeable potassium	0.690**	0.349**

**Significant at 1% level.

TABLE 4.—MEAN SQUARES VALUES FOR PROPERTIES OF SURFACE SOILS

Variance source	Degree of freedom	Sand	Silt	Clay	Cation exchange capacity	Available P_2O_5	Exchangeable cations			Organic matter
							K	Ca	Mg	
Between series mean squares	56	3199.35	1263.62	1138.50	561.08	71737	0.0936	672.83	29.96	30.9072
Within series mean squares	586	86.74	66.53	36.88	62.49	7880	0.0109	75.71	3.30	5.1861
F values		36.88**	18.98**	30.87**	8.98**	9.10**	8.56**	8.89**	9.09**	5.96**
Between great soil groups mean squares	4	11436.01	3344.56	4027.23	4343.31	444001	0.2698	4269.78	115.24	286.81
Within great soil groups mean squares	638	288.63	151.05	108.55	79.41	10751	0.0166	101.83	4.93	5.68
F values		39.62**	22.14**	37.10**	54.69**	41.30**	16.28**	41.93**	23.38**	50.51**

** Significant at 1 per cent level.

less than 5 samples were available were omitted from the correlation analysis. It is evident that cation exchange capacity and exchangeable cations were each highly correlated with clay content and with organic matter content. Cation exchange capacity, however, was more highly correlated with organic matter than with clay content. The coefficient of correlation between clay and organic matter content was highly significant ($r = 0.253^{++}$). Because calcium was the dominant exchangeable cation in Ontario soils, exchangeable calcium also correlated to a greater degree with organic matter than with clay content. The major source of potassium in soils is the inorganic fraction, particularly the clay-size minerals. Hence, the exchangeable potassium content correlated more highly with clay than with organic matter content.

Analysis of Variance

The classes in the different categories in a soil classification system are differentiated on the basis of morphological features of the profile that can be observed. Chemical homogeneity within any class depends on the degree of correlation between the chemical properties and the observable physical properties. It was shown previously that certain chemical properties were highly correlated with texture and organic matter content of soils. Analysis of variance was carried out to determine whether there was significant variability in properties between classes compared to the variability within classes. The analysis of variance shown in Table 4 indicated that the variability between series in the physical and chemical properties examined was greater than the variability within series. It is not proven, however, that for two closely related series the variation in all characteristics was greater between the series than within the series. The analysis of variance for great soil groups also shown in Table 4 indicated that even at the great soil group level the variation between classes was greater than the variation within classes at least in the properties examined.

DISCUSSION

Statistical analysis of physical and chemical data for 643 surface samples from 57 different series in Southern Ontario indicates that the series can be grouped into different populations chemically as well as physically. Soil texture is one of the criterion used for classifying soils in the field and it is an important criteria in view of the high correlation of chemical properties with particle size. The samples included in this study were taken from permanent pasture fields. However, other cultural practices can markedly change the chemical properties of soils. Evidence is presented elsewhere (3) that the use of chemical fertilizer can increase the amount of exchangeable potassium and calcium, as well as the available phosphorus content without relation to soil texture.

An evaluation of the range in properties of the subsoil as well as the surface soil within individual series and a measure of the difference required for significance between individual series is the ultimate goal. Data from more samples of many of the series are required before this goal can be achieved. The use of I.B.M. punch cards is an efficient means of statistically analysing and summarizing the large mass of data required.

This study indicates, however, that the criteria used to classify soils into series and great soil groups do indeed result in separation of the surface soils into classes that differ chemically as well as physically. A series or great soil group does in fact represent a discrete portion of the population and it has meaning in terms of chemical and physical properties of the surface soils.

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LEAF FEEDING OF DETERMINATE TOMATO PLANTS

II. EFFECTS OF UREA AND SUCROSE SPRAYS UNDER FIELD CONDITIONS[1]

D. A. SHAW[2] and R. J. HILTON[2]

Department of Plant Science, University of Alberta, Edmonton, Alta.

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Field trials were conducted to assess the influence on determinate tomato plants of urea and sucrose foliar sprays, applied separately and in equi-molar combination. Under field conditions in Central Alberta, leaf-burning usually followed urea spraying. This was most severe during dull days with high relative humidity and was mitigated by the addition of sucrose to the spray. The sucrose appeared to reduce the initial rate of urea absorption and to prolong the absorption period. The C/N ratio in leaves was temporarily narrowed after spraying with urea, due to significant increase in leaf nitrogen occurring 2 to 3 days after treatment. Effects of treatments on vegetation and reproduction were slight, and without statistical significance.

INTRODUCTION AND LITERATURE REVIEW

Foliar spray applications of certain minor elements, such as zinc and boron, have for many years been a recognized means of overcoming plant deficiencies. In recent years there has been a renewed interest in the feasibility of leaf-feeding the major elements phosphorus and nitrogen, particularly the latter, in the form of urea. The present project was initiated with the objective of obtaining basic information on the effects of nitrogen applied as urea foliage sprays on the carbon-nitrogen balance in field-grown determinate tomato plants under Central Alberta short-season growing conditions.

Brief mention will be made of literature reviewed which has special bearing on the experimental work presented herewith. Other relevant literature has been reviewed in Part I (4). Under field conditions Emmert[3] found tomatoes suffered some leafburn after urea sprays as low in concentration as 5 lb./100 gal. (approximately 0.1.M.). A report by Fisher *et al.* (2) indicating beneficial effects of urea sprays on apple trees in the field is in contrast with that of Fleming and Alderfer (3), who obtained no favourable responses where urea sprays were applied to grape vines. Work by Montelaro *et al.* (5) does not support Emmert's findings regarding the efficiency of urea foliar spray as a means of applying nitrogen. Evidence of rapid absorption by woody stems and branches has been obtained by Tukey *et al.* (9) in tracer studies.

Relative to urea utilization the literature indicates that the logical point of entry for urea into the nitrogen economy of the plant would appear to be via ammonia following enzymatic hydrolysis within the plant. Subsequent utilization in amino acid and protein or amide synthesis, depending on plant requirements, according to the generalized scheme of Gregory and Sen as presented by Nightingale (6, 7) appears to represent

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[1]Contribution from the Department of Plant Science, University of Alberta, Edmonton, Alta. (This work was carried out while the senior author was the recipient of a National Research Council of Canada Bursary and Studentship, 1951 to 1953).

[2]Graduate student and Professor of Horticulture, respectively, Division of Horticulture, Department of Plant Science, University of Alberta. (Present position of the senior author: Assistant Superintendent, Provincial Horticultural Station, Brooks, Alta.).

[3]Personal correspondence. 1952.

the pathway of urea in organic nutrition. Such a scheme is in general agreement with the results of many workers, including Chibnall, Eckerson, Vickery, and others whose findings also have been discussed by Nightingale.

If sucrose is absorbed from foliar spray it will presumably supplement the normal internal sugar reserves of the plant; no literature was reviewed which proved whether or not spray applied sucrose entered into the normal metabolic processes of the plant, though results of Went and Carter (10) and Smith and Zink (8) indicate that utilization does occur.

MATERIALS AND METHODS

The soil utilized for both preliminary and main field experiments was relatively fertile, black Malmo clay loam. The tomato variety Early Alberta was employed. This is a local and well adapted variety selected from progeny of a Bounty x Golden Bison cross.

Preliminary Trial

Transplants were set out on June 9, 1951, at 3′ x 3′ spacing, the plot consisting of three block of 30 plants each, within which three plants constituted the treatment unit, the central plant being utilized for leaf analysis. Ten treatments within each block were as follows:

1. Check—no spray
2. Urea
3. Sucrose
4. Urea plus sucrose

(2–4) —each at 0.1, 0.5, and 1.0 molar.

Block 1 received three spray applications at 2-week intervals, the first on July 28. Block 2 received the second and third, and Block 3 the third spray only. Leaf samples were taken at one and three weeks after each spray application, and analysed for soluble carbon and nitrogen*.

Main Field Test

Vigorous transplants of uniform size were field set at 4′ x 4′ on June 7, 1952, in four north-south rows of 18 plants each, plus a guard row of plants on either side and at each end of the area. The planting was laid out in a randomized block design, involving four treatments replicated six times, each treatment unit consisting of three plants. Spray treatments applied were as follows:

1. Check—no spray
2. Urea—0.5 molar
3. Sucrose—0.5 molar
4. Urea plus sucrose—0.5 molar.

The first spray was applied on July 22, the second on August 4. Plants were thoroughly covered at each application, spraying being discontinued before appreciable loss by drip occurred. Leaves from the central plants of replicates 1 and 2 were used to follow the levels of soluble carbon and nitrogen for 12 and 10 days after the first and second sprays respectively. Tests were made daily for the first 4 days and thereafter every second day. Records were taken on height and spread of plant

*The first analysis was not made because the technique of analysis was at first faulty.

(July 31 and September 8), and on total yields of green and ripe fruit on October 1, a few hours prior to a heavy fall frost; analyses (soluble C and N) were carried out one day later on representative green and ripe fruits selected from replicates 1 and 2.

Selection of leaves for analysis was carried out in a similar manner for both experiments. Leaves from the preliminary experiment in 1951 were not washed and dried to remove any external residue, as was done in 1952. Leaf samples were taken between 9.00 and 10.30 in 1951, and between 8.00 and 9.00 in 1952. An attempt was made at all times to select leaves of about the same physiological age and morphological position on the plant, mature but not senescent, and which had been unshaded for an hour or more prior to removal from the plants. The procedure used in washing, weighing and analysis of leaves has already been described (4).

RESULTS AND DISCUSSION

Preliminary Trial

Where urea spray was applied marginal leaf burning occurred and was first evident the second or third day after spray application. The amount of burning increased progressively with spray concentration and number of applications. The addition of sucrose to urea spray at equimolar rates prevented or greatly decreased leaf burn at all three concentrations tested. Total leaf injury appeared to be greatest when the weather was cloudy on the spray date, and the succeeding day or two. Plants sprayed only with sucrose showed no visible effects of treatment. The average leaf levels of soluble carbon and nitrogen established for the basic treatments during the trial are given below in tabular form:

	Analysis	
Treatment	*p.p.m.*	*Fresh-weight basis*
	Carbon	Nitrogen
Check	2547	132
Urea	3394	165
Sucrose	3272	154
Urea and Sucrose	4215	187

The chemical analyses of this test served to develop the analytical technique and to show the concentrations of soluble carbon and nitrogen which would normally be encountered under local field conditions.

Main Field Test

Results of the leaf analyses from the main field experiment of 1952 are briefly summarized in Table 1.

The data show that leaf concentrations of soluble carbon were not appreciably affected by sucrose applied alone or in combined spray. Analyses of variance of the complete carbon data disclosed no significant effect of treatments on carbon levels: ($F = 2.66$; F at 5% level $= 2.78$).

TABLE 1.—MEAN LEVELS OF SOLUBLE CARBON AND SOLUBLE NITROGEN (P.P.M. FRESH-WEIGHT BASIS) IN TOMATO LEAVES DURING TWO TEST PERIODS FOLLOWING FOLIAR SPRAYS. (SUMMARIZED DATA FROM 1952 FIELD EXPERIMENT).

Period	Treatment							
	Check		Urea		Sucrose		Combination	
	C	N	C	N	C	N	C	N
First (12 days)*	2100	280	1600	680	2200	410	2100	550
Second (10 days)**	2000	330	1800	730	2000	210	1800	610
Average	2050	305	1700	705	2100	310	1950	580

Treatments L.S.D.—Nitrogen 5%—217 : 1%—297
*Values are means of 16 determinations
**Values are means of 14 determinations

TABLE 2.—SOLUBLE C/N RATIOS*—IN TOMATO LEAVES FOLLOWING FOLIAR SPRAY TREATMENT. (ADAPTED FROM DATA OF 1952 FIELD EXPERIMENT).

Treatment	Means for first 4 days			Means for entire period		
	Period 1	Period 2	(1 & 2)	Period 1	Period 2	(1 & 2)
Check	6.6	6.4	6.5	7.5	6.0	6.7
Urea	2.9	1.2	2.1	2.4	2.4	2.4
Sucrose	7.6	7.5	7.6	5.5	9.2	6.8
Combination	3.2	1.8	2.5	3.8	3.0	3.4

*Ratios, expressed as single values, represent average soluble C : average soluble N for the interval and treatment indicated.

Soluble nitrogen levels were somewhat higher in the second as compared with the first test period, with the exception of the reverse effect in the sucrose treatment, for which no explanation is offered here. The soluble nitrogen level (average of both test periods) was similar for check and sucrose-sprayed plants, while for the combination treatment they were practically doubled, and for the urea treatment were more than doubled. These very high levels of soluble leaf nitrogen were due primarily to very large increases during the first two or three days following spray applications. The extreme example of the level to which nitrogen can rise as a result of urea spray was Day 1 of the first test period, where the analyses of two unsprayed samples gave a mean of 403 p.p.m. N, contrasted with 3140 and 1260 p.p.m. N for the two urea treatments. Analysis of variance of the complete soluble nitrogen data disclosed a highly significant effect of treatments: ($F = 8.60^{xx}$; F at 1% level = 5.09).

In Table 2 the analytical data for soluble carbon and nitrogen for the two test periods are expressed in ratios which illustrate how markedly urea, alone or with sucrose, narrowed C/N ratios, especially in the case of urea

for the first four days, as well as for both treatments based on the data for each complete test period.

A tendency toward an inverse relationship generally between carbon and nitrogen was assessed by a correlation test for the complete data for the two test periods. Correlation coefficients were as follows:

Check	$r = -0.477^{x}$
Urea	$r = -0.272$
Sucrose	$r = -0.236$
Urea plus sucrose	$r = -0.492^{xx}$

"r" for significance at 5% = 0.374; at 1% = 0.478 .

The inverse relationship apparently is the normal one, maintained where the combined spray was applied and lost to a significant degree when urea or sucrose were applied separately.

Treatment effects on height and spread were slight and the data are not shown here. It was noted that successive applications of urea opened up the foliage somewhat, permitting slightly earlier ripening, presumably due to the increased light and heat available to the fruit. In effect the urea sprays demonstrated a physical effect, similar to pruning, in advancing fruit maturity.

Fruit analysed for soluble carbon and nitrogen showed the relationships illustrated in Table 3. Thus, while soluble carbon increased as fruit ripened in the check and sucrose treatments, it decreased somewhat in the urea and combination treatments. Coincidentally fruit nitrogen was comparatively low in mature green fruits of the combination treatment, and decreased to very low levels in the ripe fruit.

There were insignificant depressions in yield of both green and ripe fruit for all spray treatments, relative to check. No adverse effects of treatments were observed with respect to fluctuations in growth periodicity, colour of foliage, earliness of fruit set and its subsequent development. Performance of check plants during the course of the experiment indicated

TABLE 3.—MEAN LEVELS OF SOLUBLE CARBON AND NITROGEN IN MATURE GREEN AND RIPE TOMATO FRUITS EXPRESSED IN P.P.M. FRESH WEIGHT BASIS. (FROM DATA OF 1952 FIELD EXPERIMENT).

	Class of Fruit			
	Mature Green		Ripe	
	Carbon	Nitrogen	Carbon	Nitrogen
Check	5700	60	8300	<10
Sucrose	5700	50	7200	<10
Urea	7400	40	6000	<10
Combination	6600	20	6000	<10

that nitrogen from the soil was sufficient to supply plant needs for normal growth. However, the chemical analyses, especially those of the leaves, show that there were distinct effects of treatments on the course of metabolism, especially in the case of nitrogen. The sharp rises in soluble leaf nitrogen recorded in from one to two days after individual spray applications of urea alone, and to a lesser extent of urea combined with sucrose, confirm the conclusion previously drawn from results of a winter greenhouse test, discussed in Part I of this paper, that spray urea was rapidly absorbed when applied alone. Absorption appeared to be hindered by addition of sucrose to the spray. Results with respect to urea absorption thus parallel those obtained by Cook and Boynton (1) and Tukey *et al.* (9). No evidence was obtained for absorption of urea from urea-sucrose spray in the greenhouse test referred to above, presumably because internal leaf nitrogen was already at very high levels (about 1500 p.p.m.) and the rate of urea absorption from combined spray was too low to push internal levels significantly higher. In the field, with adequate leaf carbohydrate supplies to make use of nitrogen, i.e. transfer it to protein, leaf levels generally ranged around 300 p.p.m., some 1200 p.p.m. lower than under winter green house conditions, and absorption of urea applied to leaves in combined spray was more readily detectable. No evidence was obtained for absorption of sucrose applied alone or in combined spray, confirming the results of work previously reported. These results are not in agreement with work reported by Emmert, and Emmert and Klinker, regarding sucrose absorption and the beneficial effects to be derived therefrom.

CONCLUSIONS

1. No evidence was obtained for absorption of sucrose from foliar spray; applied alone, it caused only slightly inconsistent fluctuations in the soluble C/N ratio of leaves.

2. When combined with urea in foliar spray, sucrose largely prevented the depression in internal levels of soluble carbon that was associated for 12 days after spraying with the use of urea alone.

3. Sucrose in combined spray acted to prevent the build-up of excessive internal concentrations of soluble nitrogen in the leaf, but did permit significant absorption of urea.

4. Use of urea in foliar spray with or without sucrose, resulted in rapid and marked narrowing of the leaf C/N ratios; the depression was striking where urea was applied alone, and was due to highly significant increases in soluble nitrogen during the first 2 or 3 days after spraying.

5. Effects of treatments on vegetation, flowering, fruit set, development, ripening, and fruit yield under field conditions were slight and without statistical significance.

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